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OUTER SPACE

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WEDNESDAY, JANUARY 22, 1958

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Congress of the United States,

Research and Development Subcommittee and Military Applications Subcommittee of the Joint Committee on Atomic Energy,

~~RESTRICTED DATA~~

Washington, D. C.

The joint subcommittees met, pursuant to other business, in room F-88, the Capitol, Hon. Carl T. Durham, Chairman of the Joint Committee on Atomic Energy, presiding.

Present: Representatives Durham (presiding), Holifield, Price, Van Zandt, Patterson, Hosmer; Senators Anderson, Pastore, Gore, Hickenlooper, Bricker, and Dworshak.

Present also: Members of the committee staff: James T. Ramey, Executive Director; Messrs. Toll, Conway, Brown, and Nelson.

Atomic Energy Commission: Dr. Raemur Schreiber, Chief of Section, Rover Project, Los Alamos Laboratory; Dr. Theodore Merkel, Livermore Laboratory; Dr. Stanislaus Ulam, Los Alamos; Col. Jack Armstrong, Deputy Chief, Aircraft Reactors Branch; Dr. Norris Bradbury, Director, Los Alamos Laboratory; W. Kenneth Davis, Director, Reactor Development Division; Louis W. Roddis, Deputy Director; Commander Moore; Bryan LaPlante; Mr. Tammaro.

NACA: Dr. Abe Silverstein, Associate Director, Lewis

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JOINT COMMITTEE ON ATOMIC ENERGY

CLASSIFIED DOCUMENT NO. 5438 (1144)

Flight Propulsion Laboratory; Dr. John C. Evvard, Chief, Supersonic Propulsion Division, Lewis Laboratory; Dr. Addison M. Rothrock, Associate Director for Research (Propulsion).

DOD: General Austin W. Betts, Deputy Director for Guided Missiles (Holiday Office); Paul Smith, Office of Asst. Secy Defense for Research and Engineering; Carl Sorgen, Office of Asst. Secy. Defense for Research and Engineering; Lt. Col. Marvin N. Stanford, Office, Asst. to Secy Defense.

Chairman Durham. I believe Dr. Ulam is next.

Senator Anderson. Have you been before the committee before?

Dr. Ulam. No.

Senator Anderson. I assume you all know Dr. Ulam was very much interested in the development of the hydrogen bomb. He probably came up with the first suggestion that led to its final development, and while another eminent scientist was always credited with the hydrogen bomb, here is the man who had the idea, and I believe your name is first and maybe the other name is second ; is that right?

Dr. Ulam. No matter; alphabetically I suppose.

Senator Anderson. Anyhow, I am very proud of the work he did and the very modest way in which he has conditioned his life thereafter.

Dr. Ulam. I am at your disposal.

Senator Anderson. Outline some of your ideas first.

Dr. Ulam. I am to cover briefly the whole situation.

I think our eminent speakers before discussed how chemical fuels are limited in energy. The nuclear energy, of course, per unit of weight is an enormous factorhigher, a million times higher. The trouble is the chemical fuels can be used fully or even to a greater extent. The reason for it is that the reactors which enable us to put out this energy are of such delicate structure and are to some extent limited in the

from the running standpoint.

One could get millions of degrees and fantastic velocities from the eflux of the propellant of the rockets; however, the rocket xxxxxxx will not stand more than 2,000 degrees.

The proposal this morning mentioned temperatures of the order in Fahrenheit of four or six thousand degrees higher than any chemical possibilities, and I want to speak of the advantage which nuclear fuel has. But there is this limit: the limit for a steady operation of reactors.

Of course, long ago, in fact shortly after the war, some of us thought how to circumvent such difficulties, making something much more simple, crude, requiring no watchmaker's precision in parts and pumps, and yet get to extremely high temperatures, extremely high velocities, and some such things that are almost obvious.

You could use the nuclear fuel not in the way you use the chemical fuel, not to heat up something else, even liquid hydrogen, which Dr. Schreiber described, which is a very good thing, but you could be really extravagant and throw out most of the fuel as you burn it.

Clearly the limits at which one can operate in this fashion are higher still. You do not need any delicacy about the containing of the material.

So one idea was simple to have what I think Dr. Schreiber

in the last minutes of this talk alluded to as the Livermore exhaustive scheme for a gaseous reator.

It would be simply, if shoved into a pipe, a big pipe, if you want to call it that, very mild inefficient bombs releasing each time only about a hundredkilograms equivalent of explosives.

Many times still much higher velocity, still much higher specific impulse and such things were considered, but only, of course, not officially or any big schemes of calculators, but conceptual.

Another scheme of this sort, quite old, was to explode -- and I will call it bombs again -- bombs outside the vehicle to give it successive pushing. It is almost like Jules Verne's idea of shooting a rocket to the moon. You do it in many stages. I should say it is all for unmanned vehicles for the time being. The accelerations are very great. By exploding such bombs on the outside you can get, velocity to the final product.

I thought I was asked to appear before you to discuss this at present more remote soudning possibilities, on which I am expressing my own private opinions, by the way, all the time, not those of the Laboratory. Dr. Bradbury might have some entirely different points of view on this thing. I do not think he has, but please remember these things are not

tied to any definite program now proceeding with dateline and money.

Nevertheless, it is high time to survey the whole field, which is enormous, if I may digress and give you my own personal impression.

This morning it was tremendously encouraging to hear about these things which are undoubtedly to play an enormous role in the whole field of missiles, and I am just waiting to answer the questions, if I may or can.

Senator Anderson. Dr. Ulam, you are regularly working in this sort of field at Los Alamos?

Dr. Ulam. No. I work on many things but happened to be interested in propulsion years ago. We wrote a few reports on such possibilities, which indeed may one day turn out to be very practical.

As Colonel Armstrong said, it is not only the question of insurance, but to do the best one can, especially since nothing is certain in this field. But one thing I am convinced of is that nuclear propulsion will play a decisive role in the next few years.

May I continue talking?

Senator Anderson. Yes. I was just going to say that one thing we would like to have you comment on is how do you think the Russians put up Sputnik. Did they do it chemically?

Dr. Ulam. The chances are. I do not know. I have no special way of knowing. From all indications it was just a very good three-stage chemical jog.

It is my own feeling, as an individual or scientist privately, there is no doubt that they must be working on things like Rover and Pluto. Both schemes described this morning are very ingeious, but by no means do they surpass those of the imagination which you would expect from highly trained physicists or engineers who are there. So my own feeling is Sputnik might be what we are working on right now. Therefore, all the effort is more than warranted, all the pressure justified. I do not know. I thought there was such a wonderful reception and wonderful feeling in this committee.

Senator Anderson. Do you think the possibility of the use of these liquids offers some future possibilities of great interest to us?

Dr. Ulam. Yes, I do.

Senator Anderson. This is a little bit like our work in trying to control thermonuclear power so we can make some use of it.

Dr. Ulam. My own feeling is in principle this thing could be done. Very soon even. They are very expensive, involving material in the amounts, say, of hundreds of kilograms per vehicle. Of course, this would be sort of a propaganda or purely science thing and not a military mission type thing

at first.

But all of these things -- as you know, the hydrogen bomb at first was an enormity, weight of 50 tons.

Chairman Durham. Dr. Ulam, we have heard a good deal abat space platforms, that whoever controlled outer space would control the world. Would you mind commenting on that?

Dr. Ulam. I have no opinions on the military aspects of a platform.

Senator Dworshak. Doctor, do you think that the demonstration of Sputnik is conclusive evidence that the Soviets are developing destructive satellites, missiles, which indicate that they are far surpassing us in this development?

Dr. Ulam. What the satellites themselves could be used for I do not know.

Senator Dworshak. Is that evidence which should be held down to that one performance of Sputnik? Or is that evidence they have gone far afield in this overall development and probably have missiles and satellites and rockets which constitute a real threat to the security of our country?

Dr. Ulam. I think it is this last. Sputnik showed they have a very good vehicle in the first stage, and Sputnik No. 2, which weighs half a ton or more, certainly could just as well be a missile. Whether they have enough of these to do anything in this year or next year, of course, I cannot tell.

But they have the technology to start developing such things.

Chairman Durham. Mr. Ramey.

Mr. Ramey. Do you think the level of efforts should be moderately increased or greatly increased, as some people have advocated, on going towards speace vehicles?

Dr. Ulam. My feeling is that the subject is of enormous importance. How much to increase the real effort right now in the form of setting up organization or making exact blueprints is not clear at all. It would be nice to have a few more brains involved in it in the thinking stages about all the possibilities of nuclear propulsion. That requires really rather enormous sums at first, and nobody knows what will happen in five years.

I remember when I first came to Los Alamos I was shown the entire existing supply of plutonium -- 14 years ago -- and the amount of fissionable material about which we talked was the head of this match. That is what happened.

Senator Anderson. When did you go Los Alamos?

Dr. Ulam. At the end of 1943. So things are not predictable.

Senator Gore. Doctor, would it not be necessary first to develop a will and a purpose and a determination to undertake such studies?

Dr. Ulam. Yes.

Senator Gore. Do we have an adequate concentration of effort in this field, in your opinion?

Dr. Ulam. It seems to me in the nuclear at least, if I ~~amy~~ may say so, right here in the Commission.

Senator Gore. Is it your opinion that a vehicle with some control of mobility in space beyond the earth's atmosphere would be a logical sequence to the successful launching of the Rover?

Dr. Ulam. It is my belief rather than opinion, but a very strong belief, yes. The time scale cannot be predicted, but not long.

Senator Gore. If that be the case, what do you think could be done in this second field, some controlled mobile vehicles, pending the successful operation of the Rover rocket?

Dr. Ulam. Do you mean a parallel effort?

Senator.Gore. How could the efforts be paralleled?

Dr. Ulam. That could be done by thinking of a few theoretical people-- I cannot tell how many -- devoted to consideration of such schemes which indeed will come. Sooner or later they will come, and it would be very good to have such. How to organize it or administer it right now is not really my province. But it should be done.

Senator Gore. Is it anyone's problem right now? Just what is being done in this particular field other than what we are doing here today ~~-- talking~~ about it?

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Dr. Ulam. There is nothing as far as I know. There might be something other in the Department of Defense I know nothing about, and, you might say, private individuals or scientists speculating about it some organized fashion.

Senator Gore. What is needed in your opinion, if I understand you correctly, is some organization, some responsible group, devoting their energy and talent and effort to this field. Is that right?

Dr. Ulam. Or even showing interest, which apparently exists. It is extremely essential. These things might have sounded visionary or bombastic a few years ago but they do not anymore. Still we need some evidence when the time comes of ability to execute ideas from paper to experiments and from experiments to building things.

Representative Van Zandt. Doctor, would you say that a project to explore space is really AEC's territory because of its relationship to the projects Rover and Pluto?

Dr. Ulam. I would say -- I do not want to speak presumptiously, coming from Los Alamos. My feeling is definitely it requires people who know about the handling of nuclear material and explosions even. This technology is confined to Los Alamos and Livermore and the people there who know the properties of this whole black magic, if you want to call it that. It seems that way.

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Senator Anderson. You say explosions?

Dr. Ulam. Explosions, yes.

Senator Anderson. I was just going to say the people at Los Alamos and Livermore have had to work with things that are very highly explosive and test them out in small explosions, have they not?

Dr. Ulam. Yes.

Senator Anderson. I recall the first time that Dr. Bradbury took me into where they were sawing up dynamite or something far more explosive, and all I was praying was that I would get out of the room alive. I had never seen somebody take a saw and run it into hot explosives. But you have to learn to handle these.

Dr. Ulam. To calculate those things or foresee what will happen if you assemble that much material.

Representative Van Zandt. I have another question. From what you say here you at least have given some thought to a project involving space.

Dr. Ulam. Yes.

Representative Van Zandt. Do you think the facilities at Los Alamos are adequate to launch such an effort or would it require an expansion of existing facilities?

Dr. Ulam. The facilities so far for the time being in going beyond Rover require paper and pencil and thinking, shall we say. It is ~~for Dr. Bradbury~~ to say whether he wants

to. I know he actually wants to hire some more people.

Dr. Bradbury. Mr. Chairman, Dr. Ulam is putting out some very important aspects of the situation. I would like to add a few remarks to it, just to sort of supplement what he is saying and what Dr. Schreiber was saying this morning. 239

When we put into the nuclerar propulsion program the Rover and the Jumbo concept -- we have described the two different approaches to the nuclear proplusion program. To get that going within the framework of our budget we had to almost entirely discontinue the work which we were doing on the sort of advanced concept that Dr. Ulam is duscussing. There are only so many dollars and so many people, and to protect the short-range propulsion program these longer-range things had to be put on a back burner.

I think -- in fact, it is quite clear -- that with the additional funds that we have been discussing, it is our proposal to go back into these advanced concepts considerably more strongly and explore them, as Dr. Ulam is saying, on pencil and paper basis, thinking, and with laboratory-type experiments.

You will recall in Dr. Schreiber's three columns this morning there were various types of laboratory approaches that were necessary for some of these things before once could attack them on a full-scale fashion. This we propose to do.

We have a small group of people that meet informally once

a week or oftener that talk among themselves about this sort of thing. The sky is the limit. No minutes are take. Let the imagination ramble. I think I would agree entirely with Dr. Ulam that any ideas, at least at Los Alamos at the moment, of a physical expansion necessary for the exploration of these more advanced concepts would be out of place.

There is definite need, definite room and definite ability, I agree with him also, to do the preliminary paper work. That paper work may tell you that the idea is not worth going ahead with. It may tell you it would be good in an experimental effort in a remote field, whatever it may be. It may bring to light some easy technique which no one has thought of yet.

But I think the idea of a large physical expansion at this point is not relevant, but the idea of definitely encouraging people to look at and worry about and think about and do whatever laboratory calculation and laboratory experimentation is concerned is very worthwhile.

Senator Gore. It would require time to think about the work and they would have to have something to live on meanwhile.

Dr. Bradbury. Of course, those people cannot be worried about the time schedule or we might have another Kiwi.

Senator Gore. Did you say TVA? (Laughter.)

Representative Van Zandt. Does it require first additional money?

Dr. Bradbury. Yes.

Representative Van Zandt. How about the authority? Do you have the authority now under your AEC directive to get into this field?

Dr. Bradbury. The Atomic Energy Commission has always been extremely kind to Los Alamos in letting them do what they want provided they came through good. So I think I have the authority.

Senator Pastore. How about getting the right people?

Dr. Bradbury. The right people are always hard to get.

Senator Pastore. Do you think you can get them?

Dr. Bradbury. We have many of them. We will want more. But the people with imagination and technical ability, with wide background in physics and mathamatics and chemistry and metallurgy, are not for sale on every street corner.

Representative Price. Have you had people out in your laboratory who for any number of years have had the imagination to foresee the developments in space?

Dr. Bradbury. You are talking to one of them -- Dr. Ulam. We have others.

Representative Price. Among the scientists you know, Doctor, are there any number of them that think it feasible now to start more serious study of the space question?

Dr. Ulam. Yes. Some reports were written on these things years ago. Some of the schemes are old, but you know the amount of material seemed astronomical 10 years ago and they

seem paltry now. And who is to say what the next few years will bring.

My own impression is that if half the things expected of Rover are true, it is an enormous thing, completely equivalent to the entire chemical fuel effort.

If you want to speak in poker language, suppose you say modestly there is one-third chance of the Kumbo working. If it works it is worth many billions of dollars. There is no question about that. So the expenditure of any effort on it is very favorable.

Senator Pastore. Do you believe in the admonition that the nation that controls outer space will control the world? Do you believe that admonition?

Dr. Ulam. It is a very general dictum and it is to be qualified with time. If some nation controls travel in space and is in possession of the moon, it ipso facto, it seems to me, dominates this planet too.

Senator Pastore. I would like to not take too much time at it because I know it is quite a panorama. But could you answer the question why that is so?

Dr. Ulam. Well, it is an old statement -- high mobility on a really astronomical scale, both from the point of view of surveying and gathering intelligence. And then you can have, if you want to, missiles against which very little defense would exist.

Anyways, the future as a whole of manking is to some extent involved inexorably now with going outside the globe. Airplanes have done a little bit in this direction. Recently we have been going a hundred miles on exploratory vehicles. There is no question in the next 10 or 20 years the whole aspect of things will again change. It does not take any special prophet to say that.

Representative Patterson. Do you think within 10 years, Doctor, there will be actual travel in space?

Dr. Ulam. By travel, you mean vehicles without people in them?

Representative Patterson. No; with people in them.

Dr. Ulam. Well, my guess, just guessing, extrapolating from past history and technology, is that within 10 years there might be living beings or perhaps humans going around the earth. Whether somebody will return in 10 years, I would not hazard a guess. But in 20 or 30; sooner or later.

Representative Price. You mean going around the earth and safely landing?

Dr. Ulam. Perhaps, yes.

Representative Holifield. You spoke of one-third chance on the Jumbo. I assume you meant it was a chance of one to three it was that good?

Dr. Ulam. Yes.

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Representative Holifield. Doctor, in speaking of these things you have testified about today, could you give us a comparison as to what the chance was to accomplish the atomic bomb and the hydrogen bomb? In other words, relate the things we are talking about today in terms of probability to those projects at the time you had to go into them.

Dr. Ulam. It is very hard to estimate what the chances turn out to be, but I remember in Los Alamos during the war years there were many doubts whether the things would fizzle out, doubts based on technical arguments. It was not at all sure there would be an enormous explosion.

Representative Holifield. You are speaking now of the atomic bomb?

Dr. Ulam. Yes. The hydrogen bomb was still at its inception a more chancy project. In fact, the original schemes which were entertained theoretically did not work out too well. So it is hard to put a numerical value on it, but there was never any certainty at all.

Representative Holifield. Would it be making a reasonable statement to say that in the stage of technology we are in today some of these projects we have been talking about have more likelihood of being brought to reality than was the likelihood of bringing the hydrogen bomb into reality at the inception of the project?

Dr. Ulam. I would think, based on present knowledge, it is to my mind a certainty that some method of nuclear propulsion will work and be much more powerful or important in the long range than anything else. About any specific method discussed so far, one cannot have any certainty, but one way or another the problem will be solved is my private conviction.

Representative Holifield. As I remember the specific theory of the hydrogen bomb was not the one that finally became the reality.

Dr. Ulam. That is true.

Representative Holifield. It was a breakthrough in joint efforts between you and Dr. Teller that brought a different concept into being the hydrogen bomb, was it not?

Dr. Ulam. That is true.

Representative Holifield. Could you refresh our minds as to what that breakthrough was? I was out at Los Alamos, Dr. Bradbury, you remember, at the time when the theories were explained to us, and I believe Dr. Teller and Dr. Ulam were there at that time when our subcommittee was at there.

Dr. Bradbury. This is a subject which, of course, is quite off the path we have been following, and I want you to assure me everyone in the room should hear this.

Representative Holifield. I withdraw it, although I think everyone is cleared.

Dr. Bradbury. It ~~is a weapon matter~~. I am perfectly

willing to describe it, but it might offer a problem.

I think the point which you are making, though, is extremely well made, the same as Dr. Ulam is making, in that the obstacles to be overcome in the first atomic bomb and the hydrogen bomb seem now to be very large compared to the obstacles one has to overcome in going about nuclear propulsion. It looks to be a much better bet. Whether a similar breakthrough that we have not seen yet and do not really seem to need in the nuclear propulsion tests is right around the corner, no one knows, of course.

Representative Holifield. This is what I wanted to clarify in my mind: that the general feeling among the scientists is that there is greater likelihood or chance of doing these things than there was at that time for those things.

Dr. Bradbury. Enormously so, compared particularly to the hydrogen bomb. For many years no one saw any way of licking that at all, let's say reasonably. I think one sees the way to like everything foreseen now.

Senator Gore. Let me see if I understand you correctly. If I do, I think you have made a very arresting statement, Dr. Ulam. Did you not say, in answer to Congressman Holifield, that this undertaking of space vehicles appears now more feasible than the hydrogen did when you first began the effort?

Dr. Ulam. You extended my remarks rarther than my remarks, I wished them ~~to extend~~, but that is probably true. I was talking about the means of nuclear propulsion like

Pluto and Rover.

Dr. Merkle. Rover is a good machine, real good. It is no slouch.

Dr. Ulam. There are going to be other tough problems to solve once you solve the immediate Rover sort of application, problems of getting back home, landing, and things of this sort. I think what you said is true, but I was talking about something not as spectacular as you are talking about.

Senator Gore. You still say, though, what I misunderstood you to say is nevertheless true?

Dr. Ulam. I think it is true, yes.

Senator Gore. I think that is something to which this committee must give attention.

Representative Price. Do I understand you, Doctor, that now at Los Alamos there are groups doing some talking and maybe some paper work along the idea of space propulsion?

Dr. Ulam. Yes.

Representative Price. What size groups are they?

Dr. Ulam. Some are informal of, let's say, 15 people discussing things theoretically. It is not yet at the stage where they propose definite experiment, although it is clear what kind of experiment should be done.

Let make this remark: In general the Los Alamos and Livermore Laboratories are oriented toward making as big an explosion as possible for ~~military~~ uses. This field will have

to learn the details and the precision of making small mediocre explosions, more in the nature of burning almost, in order to eject the material, not at the fantastic temperatures of a hundred million degrees but rather some of the order of 8,000 or 10,000. These figures are already very impressive.

Representative Price (presiding). Are there any further questions of Dr. Ulam?

Thank you very much, Doctor, for your presentation.

Dr. Merkle, we would like to hear what you have done at Livermore.

Dr. Merkle. You are interested in hearing what we have done at Livermore about some of these advanced concepts?

Representative Price. That is right.

Dr. Merkle. As Dr. Ulam indicated, not much manpower is being invested in the country in this sort of scheme. We have broken down the problems of other schemes than Rover into several categories, and over the past year and a half we have been attempting to establish, by means of the basic laws of physics and the fundamental cross sections of various kinds of matter, those schemes which appear to have some hope of working and those schemes which appear to be prohibitive from one way or another.

The schemes that we have considered include the gaseous

reactors, exploding gaseous reactors or pulsed gaseous reactors, bomb explosions under confinement, combusion of sticks of fissionable material, and the ion rocket. These are the principal ones that we have considered.

In all of the cases except the case of the ion rocket we have been able to show to at least a cursory degree that the schemes are very far away indeed, so far away that we do not see on the face of it an easy way of attacking the experimental problem.

We have also, in the course of doing this, made some modest studies of what you can actually do with Rover-type devices if you are willing to double stage them, and we have used the double-staged Rover as a comparison with these other schemes in attempting to estimate the real relative difficulties of the task and the real relative goals that could be attained.

Let me say the conclusion is very briefly as follows:

If you are interested in navigating in the solar system from the earth to the Moon, to Mars, to Venus, in short, anywhere short of Jupiter, it looks like a two-stage Rover is the most economical, most straightforward, and most do-able way of accomplishing your desires. If you wish to go to the nearest fixed stars, something new will have to be learned. If you wish to go beyond the orbit of Jupiter, it is quite

possible that the ion rocket would be the most reasonable vehicle to attempt to develop.

Mr. Ramey. Would you describe the ion rocket?

Dr. Merkle. The ion rocket is kind of an interesting thing, which might in someways come natural to Livermore.

The ion rocket is essentially an accelerator. The power for the accelerator comes from Kiwi reactor or others, and what you are shooting out of the rear end of this system are charged particles instead of the hot gases normally shot out of the standard Delaval nozzle.

The point in doing this is to raise the velocity in which you exhaust the matter that is being thrown away. It is a fundamental principle of rocketry that the faster you throw anything away, the less material you have to have to throw away to attain a given velocity in the payload.

So in principle, if energy is unlimited, you can then throw away a small amount of matter at very high speed and propel a vessel at a very high speed.

This is the sort of goal that the ion rocket keeps dangling in front of you. But with every goal there is always a gimmick. In the case of the ion rocket it has to do with the fact that you must find some means of converting the nuclear energy in the nuclear reactor into electricity, which is lighter than our present lightest electrical generators if the scheme is to be really competitive with the Rover device.

We have made some studies of the performance of this type of device under the assumption that you could get as much as one horsepower per pound of machinery, which incidentally is optimistic by a factor of 4 over present technology. Assuming the weight of the ion rocket is substantially trivial, which we believe it would be, with that type of ion rocket you begin to get a payoff for missions from orbit stations around the earth to such things as Jupiter. With closer missions, it does not compete very well with the Rover scheme.

Senator Hickenlooper. What appropriateness this question has I am not sure, but you said a factor of 4 on the pound per horsepower?

Dr. Merkle. Yes.

Senator Hickenlooper. It runs in my mind that our internal combustion engines, the most efficient, may develop a horsepower for less than a pound.

Dr. Merkle. Indeed they do.

Senator Hickenlooper. Is there anything relative in this question as to a factor that could be applied as to how many horsepower from this electric generation to the accelerators, how many so-called horsepower might be absolutely necessary to project the vehicle as compared to the horsepower in the atmosphere and on the earth on the highway? Is there any comparison?

Dr. Merkle. There is not any very easy comparison of

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that. That sort of electrical machinery is notoriously heavy per unit of power transmitted through it compared to internal combusion machinery, turbine machinery and the like. I am not sure this has to remain eternally so. This would be a nice field for research, but it is a research that would not specifically have to be directed towards space travel.

Senator Hickenlooper. I was thinking about under the present concept, the magnitude of operations, size, weight, and that sort of thing.

Dr. Merkle. These things can be adjusted to suit your fancy. What really counts is not how many thousands of horsepower or millions of horsepower, but horsepower per pound of structure. This is the kind of thing, and I have already given you the kind of an answer -- for an ion rocket working in the neighborhood of a horsepower per pound you can extract a reasonable mission. If you want to go as far as Jupiter and if you are willing to take off from an orbiting space station. Incidentally this kind of device cannot take off from earth's surface, and probably never will.

Senator Gore. You mean ion?

Dr. Merkle. Ion rocket.

Senator Hickenlooper. I suppose it is pretty much in theory.

Dr. Merkle. That is pretty much in theory, yes. These types of considerations have been made with very limited man-

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power, and so far we have not found anything partialarly attractive that would indicate one would want to put a lot of horsepower into it in the near future.

However, I would agree with Dr. Ulam that, in general, it is very nice to have a lot of people -- a lot being 5 or 10 -- at a given laboratory seriously considering possibilities, particularly from the viewpoint of delineating the areas of the possible with the existing science.

You see this is not a matter of inventing devices; it is more like the situation that prevailed in about the year 1700 when the first law of thermodynamics was vaguely understood by some and not at all by others, and all the inventors in the world were trying to invent a perpetual motion machine. A lot of brain power went into that. What you have to go after in that case is the fundamental limiting of matter and energy, which sets the ring of what you may consider.

Senator Gore. You find yourself in agreement then, as I understand, with Dr. Ulam and Dr. Bradbury, that what is needed is the creation of some group that can devote its talent and its energy and its thinking to fundamental research in this field of study?

Dr. Merkel. I would go one step further than they have already gone, and I think they will agree with me on this step: that if you wish to have such a group function effectively,

it functions best if it is an adjunct to and associated closely with an existing nuclear propulsion program that gives it the technological resources to draw on, both from the standpoint of the engineering considerations, scientific matters, and possibly experimental determinations of small points as they come along. It is very hard to imagine a group of 10 or 15 people isolated in a room some place thinking about this thing creatively over any extended period of time. They kind of run dry. But if they are closely associated with a program which is practical and which is operating, that practical program continues to bring up problems and ideas and whatnot which stimulates further development.

Senator Gore. You have the Rover project in mind?

Dr. Merkle. That is a beauty.

Senator Gore. Or Ramjet?

Dr. Merkle. Ramjet does stimulate thinking of this sort. It gets one acquainted with the power densities at which you can run materials, for example. It gets you thoroughly acquainted with the neutronics of reactors. It browbeats you with heat transfer problems so you have a feeling for them in your bones. Many inventions you can cook up on a sort of theoretical basis fail because you overlook some very perfectly obvious thing that is known to the guy across the hall, so to speak. So you need to have the guy across the hall who is

working in these various areas all the time so you can ask him questions in his particular sector.

Representative Van Zandt. Would you, therefore, suggest that in addition to a group functioning at Los Alamos there should be another group functioning at Livermore?

Dr. Merkle. Of course, being from Livermore, I would suggest such a thing certainly. Incidentally, I think it is a very good thing, and we are doing a little bit.

Representative Hollifield. Based on the same principle you just stated?

Dr. Merkle. Based on the same principle, and it has been surprisingly productive for the amount of effort that has gone into it.

Representative Holifield. This does not really take a great deal of money at this time to do this type of work, does it?

Dr. Merkle. A man-year at Livermore costs about $22,000. If you were to devote six men to this thing, that would be a very large effort at this stage of the art.

Representative Price. How long do you think it will stay in the imagination period and until it will start in the hardware stage where you do need a lot of men?

Dr. Merkle. I think the imagination stage is essentially the mapping period. What we are really trying to find out is

the nature of the terrain in which such inventions are possible and the nature of the terrain in which such inventions are not possible, the latter being the heavier part of the effort. It is almost as important to know what you cannot do with existing physics as it is to try to invent what you can do with it.

This kind of stage might last a long time or a short time; it is hard to predict when something might turn up. When it turns up, then it is time enough to worry about expanding some kind of a hardware program around it.

As I say, at the present moment we see nothing at Livermore at any rate which would justify a hardware program at all. It is still a study project, maybe a few laboratory type experiments. We are doing one on the centrifugal separator concept, for example.

Representative Price. Would the same be true at Los Alamos, Doctor?

Dr. Bradbury. I would agree very much, yes.

I think one thing is apparent in the time scale. You will have to solve the Rover problems first. That problem, as you heard this morning, is a problem which is pointed toward feasibility in the early '60's. Once you have solved the Rover problem, per se you have automatically at your hands the way to make a massive satellite; once you have a massive satellite you can go to the moon.

Then you can have any solar system type of satellite operation you want to do. I will not be optimistic and say you can get back to the earth. We are pointing at a time scale then for satellite type of operation -- I mean massive satellite -- some place, it seems to me, in the sixties.

Representative Price. You say then the space ship is tied directly to nuclear propulsion?

Dr. Bradbury. The first space ship.

Representative Van Zandt. Primarily Rover?

Dr. Bradbury. Nuclear propulsion, which is Rover. The kind of thing I am talking about is something which will do more exotic things, go farther or faster, something of that sort. It is a thinking operation, an idea operation.

Representative Holifield. Then if there was a stronger concurrent effort along this line, that could proceed without any deletion of your people from existing projects, but it would more or less give you another phase to think about as you go along in the Rover project?

Dr. Bradbury. It is the next step.

Representative Holifield. Can you do something concurrently if you have this project in mind as you go along on this other trail?

Dr. Bradbury. Right.

Representative Holifield. So you do not have to wait

until the end and then start?

Dr. Bradbury. That is what we are trying to avoid by adding to the effort now, the massing of effort you describe. We are trying to do that now. The effort at Los Alamos, at least, had to decrease almost to zero -- not quite -- to put the two parallel concepts for Rover into being, and with the funds we are talking about for 1959 we will again put it back into very active operation by adding people.

Dr. Merkle. I would like to make a point here. I think there has grown up a small confusion about these matters of space travel. I said a little bit earlier that if you wish to confine your attention within the solar system planets lying near the earth, principally Mars and Venus, and also a satellite on the moon, that the Rover system in a double stage version will do anything you want. That is a fairly firm statement, and it carries the usual provisos. Assuming that the Rover program is reasonably successful -- and Ihave no doubt it will be -- the only question is when will it be. And that could be a fairly long question. Therefore, one does not need to reach into the area of exotic propulsion schemes in order to do more space travel than any of us here will ever live to see.

I think this point should be firmly established. The Rover device is a very good device for space travel. At this

stage of the game you do not need a better one, and in all probability for many years to come you will not be able to find a better one.

This is part of the mapping operations. We have a few probes out into this vast unmapped terrain, and those probes when they come back always keep saying, "Yes, but Rover will do it too and for not any more money, and a lot more certain technology." It is this kind of thing.

So if you are really talking seriously about landing a man on the moon or landing a man on Venus or landing a man on Mars, which is an enormous mouthful of undertaking, you need not wait until someone invents an ion rocket, or an exotic propulsion scheme. If you want to do it, the concepts are with us now. I think this point kind of gets lost.

Senator Gore. Let's look at it a little different way. Suppose your aim is not to land a man any place but to give him some controlled mobility in space; Would not that which you have just said apply with equal truth?

Dr. Merkle. It would apply with equal truth; that is, if you wish to have a multistaged rocket system, for example, and let us have Rover as the first stage, a big Rover, which is capable of throwing this thing onto a very high orbit. And this is not much harder to do than the Sputnik orbit. Once you make any orbit, you have got practically all of them made.

Senator Gore. Once you develop a nuclear reactor or engine that will put a missile into an orbit, then you have got this question of mathematics and dynamics to develop a different sized one?

Dr. Merkle. That is right.

Senator Gore. Go ahead.

Dr. Merkle. That is to say 90 percent of the problem is done when you put a very big satellite on orbit. The remaining part, to be able to steer about in space, taking your time while you are doing it, can be handled by both chemical and nuclear systems.

Senator Gore. By some supplementary sorce of energy?

Dr. Merkle. By some supplementary source of energy, Senator, in that day you would also know how to do. It requires no exotic new invention for that either. The lovely thing about having once gotten on orbit is very little energy is required to move you any place else if you are willing to wait a while.

Representative Patterson. Is there any theory that states after you get a certain distance from our earth in space then the atmosphere becomes comparable to the one we live in now?

Dr. Merkle. I am not sure I quite understand your question.

Representative Patterson. I do not know just how to put

it myself.

Dr. Merkle. Let me put it this way: The earth's atmosphere which you are currently breathing gets thinner and thinner as you increase the distance from the earth.

Representative Patterson. When you arrive at a certain point, then does it reverse itself?

Dr. Merkle. No indeed, sir. After you get up a few hundred miles the atmosphere disappears and it never again reappears. Space is truly empty.

Representative Patterson. Then is there a possibility of going beyond space when you say a rocket that goes to the moon? What is the atmosphere, if known, within the area of the moon?

Dr. Merkle. On the moon there is no atmosphere; none.

Representative Patterson. That is what we think now?

Dr. Merkle. As far as astronomical observations can carry it, and they are quite good, there is none. On the other hand, on Mars there is an atmosphere which in composition is a little less desirable than the atmosphere at the top of Mt. Everett. On Venus there is a fairly dense atmosphere, but it is masked from view by heavy cloud cover and its composition is not known. We do not know whether there is any oxygen on Venus, for example. There is some on Mars -- presumably not enough to support a human being to try to breath standing on the surface of the planet.

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But these atmospheres are like thin skins on the surface 262
of the planets themselves, and between the planets it is just nothing at all for all practical purposes.

Senator Gore. Doctor, how much of this rocket missile research is being done by Aerojet or other private companies? Or is it all being done by the Atomic Energy Commission?

Dr. Merkle. You mean investigations into possible --

Senator Gore. I mean exploratory research that will eventually give us rockets and missiles and these satellites. Is all of that scientific work being done now by the AEC and its agencies, or are private companies contributing something to that?

Dr. Merkle. So far as I know -- and I may not know about all of the effort -- there is the Rover effort at Los Alamos; there is the Pluto effort at Livermore, both devoted to nuclear propulsion. There are pieces of nuclear propulsion efforts at at least two other commercial contractor establishments supported by the Air Force funds, I believe, and there are any number of individuals who have, as a hobby, considering these matters -- some at commercial organizations, some at universities, some at national laboratories, and the like.

Senator Gore. The preponderance of the work is being done by the AEC?

Dr. Merkle. I would say the preponderance of the work is being done under ~~AEC control~~, yes.

Colonel Armstrong. I would like to add to that, if I may, we have contracts out of General Keirn's office at AEC with North American, Rocketdyne, and with Aerojet, which contracts are to do work on the components beyond the reactors which are being worked on at Los Alamos and at Livermore. So we have a partnership arrangement here, whereby those who are competent in the nuclear field are working on the nuclear field and those who are competent on the pumps and tanks and things that must go along with are doing that.

Senator Gore. Thank you.

Representative Price. Thank you very much, Dr. Merkle.

Dr. Merkle. Thank you.

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Representative Price. Now the committee will hear from the representatives of the NACA. The AEC people who desire to leave may do so, but you are perfectly welcome to stay around if you want to.

We will hear from Dr. Silverstein, Dr. Evvard, and Dr. Rothrock. Which one of you gentlemen will handle the presentation to the committee?

Dr. Silverstein. I am Abe Silverstein, and I will make the formal presentation.

Dr. Evvard and Dr. Rothsock accompany me.

Representative Price. Dr. Silverstein is associate direction, Lewis Flight Propulsion Laboratory. Is that right?

Dr. Silverstein. That is right; NACA.

Representative Van Zandt. Is that at Cleveland?

Dr. Silverstein. That is right; Cleveland.

Representative Price. You may proceed, Doctor.

Dr. Silverstein. Not having been here for some of the other discussions today, I do not know how much of the material I present will overlap what you have already heard and how much will disagree with what you have heard.

Representative Price. Some of the material may be overlapping, but we would like to know what your organization is doing in the program. In that sense, then, it will not be overlapping.

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Dr. Silverstein. I thought that I would go throughsome of the concepts here in the space flight, bringingout some of the important items that I think need to be clarified. Perhaps these have been brought out already, but let me repeat them.

We have two major phases of propulsion. This is a subject NACA deals with at its laboratory, and Lewis Laboratory I think is the foremost laboratory in the country in aeronautical propulsion. We have worked with all the booster engines and rocket engines coming along with the propulsion scheme with the possible exception of the Rover character. We are working in the ~~neulear~~ engine field.

In space propulsion, which is the principal thing, there are two main phases. One is the booster phase. We have to have some system to put objects into the satellite orbit, and these will generally be of impulse character. By impulse character, I mean the thrust will be delivered in major pulse ~~and after that the rocket will be up to speed, and after which it~~ will reach a speed, for example, of 25,000 feet per second, which will put it into an orbit around the earth.

Once you are in this satellite orbit you can go on to an entirely type of propulsion system. Then you can go to what we call a low thrust propulsion system because the gravitional force is now balanced by this centrifugal force associated with your path around the earth. ~~So that the gravity-free system is~~

~~these~~ and no large forces are required to overcome gravity. Therefore, we may accelerate the vehicle with very little force.

Let's have our first slide here.

This initial phase I will discuss first, which I call the booster phase. ~~This is a~~ phase, ~~if~~ you are on the earth and your are going to take a path up into some type of an orbit around which you will act as a satellite, ~~and this~~ orbit, of course, can be at any arbitrary altitude. I have shown 300 miles here.

For this phase we are going to use some form of impulse propulsion. It can be chemcial propulsion, such as the Russians used to put up ~~there~~ Sputnik, or it may be the nuclear propulsion system, such as the Rover system as has been recently described here, I gather.

It is quite clear now that there are chemical systems possible for this job of boosting into the orbit that can prpvide us very much larger ~~systems in an orbit~~ than we are presently thinking about. These are advanced chemical systems. I would like to show you some of these very briefly, ~~the characteristics of them~~.

A very important one is a combination of fluorine and hydrogen in a chemical rocket. We burn these materials in the rocket and provide what we call high values of specific impulse. That is we get a lot of thrust for each pound of fuel

we burn. Looking at the~~se numbers~~, I have shown two different rates ~~up here~~ which characterize basically two different altitudes. ~~This is~~ sea level and ~~this is~~ up in the very high altitudes near space.

These values you see here, 460, are approximately twice the current values we are measuring ~~on~~ sea level ~~values~~ for the liquid oxygen and hydrocarbons ~~such as the fuel~~ we are presently using in the ICBM missiles.

The range or load carrying capabilities of the rocket goes ~~about~~ the square of this value. So if you double the value of the impulse it takes four times as much load. So it gives us great possibilities of taking quite high loads in high impulse rockets.

The work we have doing recently is to study ~~fields~~ fuels that have high impulses.

Now the next slide (Figure 3) shows some of the values we are getting in an engine like this burning these very exotic fuels. But liquid hydrogen and fluorine are liquified gases; they have to be maintained at extremely low temperatures -- for example the temperature of the hydrogen ~~here is~~ down around minus 400 Fahrenheit; flourine around minus 26. One nice feature is that the combination ~~it~~ is very reactive and has given already in the initial work figures of 93 or 95 percent of theoretical values.

So it seems to be quite clear in a very short time we will be able to get even ~~closer to~~ theoretical values. These values are

At altitude the values should be

at sea level. Up ~~here~~ around 440. ~~We rockets that have an overall density~~ there is ~~not much difference than our~~ from the present LOX - JP rockets we are using for the missile program.

Representative Holifield. Are you planning to differentiate between liquids and solids in your presentation?

Dr. Silverstein. In this presentation I have no, but I can discuss it if you choose.

Brepresentative Holifield. Just give us a little bit of a comment, if you will. I know your difficulties in your liquids. I understand there is less difficulty in the solids. Could you comment on that?

Dr. Silverstein. Yes, that is true. This is the present state of the art. There will always be more difficulty in reaching these very high values of specific impulse no matter whether you go to a solid or a liquid. However, in attempting to take large loads into satellite orbit and to really advance this field rapidly, we have to take aboard the difficulties of the fuel when we do it. In other words, the difficulties, for example, of handling hydrogen and fluorine I do not think are of the same order of magnitude, either from a development point of view or from a use point of view, as those taken aboard when you take on the Rover program. They are of different order.

Representative Holifield. Let's confine it to solids.

Dr. Silverstein. current Solids in our program have no ~~opportunity in our program or~~ chance of getting up into these high values of specific impulse.

Representative Holifield. Do you not think it was a solid the Russians used?

Dr. Silverstein. I do not know, sir. I do not know.

Representative Holifield. Would you be inclined to speculate? Most scientists I have talked to speculate they think it must have been a solid.

Dr. Silverstein. I really have no basis for making a judgment.

Representative Holifield. I was not here this morning. They say that the scientists testified this morning it was liquid more than likely.

Dr. Silverstein. I would guess the liquid, but I have no basis for it. It would be pure guess.

Representative Holifield. All right.

Dr. Silverstein. Let's go to the next slide here now.

(figure 4). This is an interesting slide showing the relations I mentioned previously. If we are going to take a load ~~for example,~~ into a satellite orbit ~~a load~~, you can greatly reduce the gross weight of the rocket you are sending up ~~to this ratio (indicating)~~ both with respect to the present fuel that we are using for our ICBM's and IRBM's, and with respect to these future solids, the best we have been able to conceive so far.

I am not saying the solids are ended here, but I am saying the state of research right now is such we do not have any better than this you can see. The ratio here is about 3 to 1. That is the reason we are very much interested in ~~this~~ the hydrogen-fluorine combination and see it as a very potent method for carrying substantial loads into an orbit, and I think preceding the possibilities of doing it with nuclear power.

I think the time scale is all important here, and I think one leg of this overall program needs to be stressed.

Representative Van Zandt. Doctor, do you think this combination of fluorine and hydrogen is the final combination of liquid fuels before you move into the nuclear power?

Dr. Silverstein. Yes, I think it is. One nice thing about chemical propellants is you can calculate. We know the whole spectrum of chemistry now. We do not think we are going to get new elements in the thing. You can calculate the heats and energies and predict the values very accurately. I say yes.

There is one further opportunity, and that is to use ozone with hydrogen instead of fluorine. This is very questionable. I doubt perhaps whether we will try it. We are doing a little bit of work on it, not throwing it out. But I doubt if it will come through.

Representative Van Zandt. What is the recent announcement -- not too recent, a month or six weeks ago -- the Russians made concerning a new type of chemicals for fuel purposes?

Dr. Silverstein. These were garbled press reports, I think. There was a mention of boron. How it got into this thing I do not know, but I think boron does not fit into this picture too well.

Representative Van Zandt. They mentioned chlorine and boron, did they not?

Dr. Silverstein. Newspaper reports I read mentioned boron. I think it was the interpretation by our own press people.

Representative Price. Did one large American chemical manufacturer announce some work in the field of boron, and that that was the latest?

Dr. Silverstein. There is some work going on. This is for gas turbine engines. There is a possibility in solid rockets using some boron hydride, and this increases the impulse of solids up to perhaps a value of 270 as compared with the numbers I showed before.

Representative Price. When you get into this rocket stage boron is not in the picture; is that right?

Dr. Silverstein. It can be in a small way in the solid field, and is in the picture, but not in a big way.

May I have the next slide. (Figure 5)

These are the kind of things we are going to want to do with space propulsion applications. I think you have discussed some of these and I will not spend much time on them. We are trying to increase the lifetime of low altitude satelittes. We

want to control and alter satellite orbits, and think a little about auxiliary power.

Let's go ahead ~~,~~ to figure 6. This moon landing I put on here simply to show you some of the velocities we are after. For satellites it is 25,000 feet per second. If we are going to land on the moon and do a reconnaissance ~~[illegible]~~ flight around the moon, we ~~[illegible]~~ can start from a satellite orbit and leave with velocity of 10,000 feet a second. We have already got 25 and if we add 10 it gives us 35, which enables us to go to the moon.

Now if we reach the moon, when we come to the moon we have to put in another velocity here of 22000 feet a second, for orbiting around the moon. We have to carry this capability in the rocket fuel with us to provide this velocity, and if we wish to land we have got to put on another velocity, the component of ~~5200~~ 5700 feet ~~[illegible]~~ per second. This is slow-down velocity. We got ~~[illegible]~~ out of the gravitational field of earth and are now going to drop into the moon unless we ~~[illegible]~~ slow it up. We are being attracted now by the moon and we have to push ~~it out~~ against its gravitational field.

To get back ~~again~~ to earth, we have to again add another ~~9,000~~ 7,900 feet a second in two steps: 5700 to get into the satellite around the moon and 2200 to get back ~~out~~ to the earth satellite. I simply showed the numbers in order to give you a feeling for the kinds of velocities we are talking about in these missions.

I mentioned there were two different types of propulsion once you are on ~~orbit.~~ There is the impulse type where you

put all the energy in at one time such as we are doing in ICBm and IRBM.

These are nuclear rockets or conventional rockets. ~~but~~ There is also The very low thrust system in which a constant small amount of energy is put in continuously. ~~this very low thrust stem. This is the kind of orbit~~ Figure 7 shows that with the orbit required for ~~an~~ a constant thrust system to get to the moon, ~~might take~~ it might take 83 days. ~~It would not~~ You would not use this system in going into the moon. You have to circle around very slowly because actually the thrust force you are putting into that vehicle is only one ten-thousandths of its weight. So you can see it is a very small force in terms of its weight, and therefore, velocity is increased very slowly.

For example, in ICBM's to take off the ground we put a thrust in that is 1.4 times its weight, in the low thrust system the ~~This is 10 to the minus four~~ thrust to weight ratio is 10 to the minus four, or one ~~or one~~ ten-thousandth. So you can get a feeling for this. However, for missions other than perhaps going to the moon these things will ~~become vey~~ become very important.

Let me have the next slide. (Figure 8)

This is a good way of also getting a feel for the different types of systems we are talking about. ~~Through here we talked specific impulse, you see, and we have talked about some velocities, and these are jet velocities and power, and~~ By this slide I am going to try to indicate to you the main problems in these new systems.

In the first column ~~Now these~~ are the kind of systems we are discussing. ~~familiar with.~~ We are familiar with the turbojet engines. You can see here we burn about a half a pound propellant per second per pound for a 50 pound thrust. (Second column).

Coming down the second column ~~here, you see these~~ numbers are gradually

reducing.

~~Over here we find another column, which~~ In the fifth column is the jet power in kilowatts. Now why is this number so big? It is big because of the jet velocity. You see the jet power comes as the result ~~sq~~ of this jet velocity multiplied by the mass of propellant. Whereas we have in the fourth ~~this~~ column a low jet velocity in the turbojet, we have a very high jet velocity here in our ion rocket.

There are two things we learned from this. One is that the fuel consumption of the ion rocket is very low. However, the power that has to be delivered to produce these velocities is very high.

I think all of you are familiar with the fact that if you are going to fly an airplane or anything else, and depending how far you want to fly it, there are two terms that are important. One is the weight of the vehicle and the other is the weight of the fuel. So that the same thing is happening here.

If we want to stay in the air a very long time, such as would be required for a mission to Mars, a thousand days or twelve hundred days, we want a low specific fuel consumption, that is, we want to burn a very small amount of fuel; and we do that by this system here, you see. (nuclear-electric ion jet) We have a very small fuel consumption.

On the other hand, to produce this velocity of 640,000 feet per second, we need a ~~we need a~~

very heavy article because we are providing a lot of power. ~~These powers here~~ weights I think will be roughly proportional to the ~~weights of the objects~~ power required ~~that are required~~, that is, one pound per kw or 10 pounds per kw, for example.

This determines the weight of the power plant, and ~~these~~ the second column determines how much fuel you use, and this is the justification for going into these very low thrust, low specific fuel consumption engines that have high initial weights because we want to stay out a long time.

Now for short missions -- by that I mean missions such as circumnavigating the moon -- there is no purpose in using an engine with this type of characteristic. (The ion rocket.) For missions such as the Mars mission ~~perhaps~~ Perhaps you can show a good relationship between the low thrust engine which accelerates very slowly and gradually takes you out to the Mars orbit.

Representative Holifield. Give us the contrast between that liquid fuel rocket in the next step there rather than the third step.

Dr. Silverstein. This is the liquid fuel rocket here.

Representative Holifield. Yes.

Dr. Silverstein. And this step here? (nuclear heat transfer rocket),

Representative Holifield. Yes, clear across.

Dr. Silverstein. Here you see that the nuclear rocket ~~item here has a~~

weight, a jet power of 1310 as compared with the 458 for the ~~at this~~ high energy liquid fuel rocket ~~point here~~. Specific impulse for the chemical rocket is 420 here. ~~Here it is 1200.~~ For the nuclear heat transfer rocket it is 1200.

Representative Holifield. It runs about three times, does it not?

Dr. Silverstein. If you take the temperatures up to about 5,000 or 5,500 Fahrenheit, the impulse is around 1200. I think you have probably heard this number sometime today.

Representative Holifield. We heard a figure of around 2700 Fahrenheit, which is what they consider a reasonable goal at the present time.

Dr. Silverstein. That would put you in the same ball park. I think that is probably for Pluto, for the Ramjet not for the rocket. I think the rocket numbers probably were 4500 and 5000, because those were current.

Representative Holifield. Yes.

Dr. Silverstein. The reason I showed this, I think, is that we have a whole spectrum of power flights here with all of the different characteristics. These ion type propulsion systems have their own characteristics -- very low specific ~~fule~~ fuel consumption, do not carry much fuel along. What ~~do~~ they have in high initial weight ~~(inaudible)~~ is compensated by the high specific impulse.

The impulse rocket, on the other hand, burns many times more ~~fu~~ fuel than those rockets with the higher initial weight. That is always the comparison to make. ~~It~~ Selection of powerplant will be determined largely by the

length of flight we want to make.

~~This will be the breakeven point.~~ Later I have some mission studies to show how our studies at Lewis Laboratory tend to weigh these things.

~~The next slide.~~ figure 9, ~~This~~ shows a comparison ~~here~~ of two different ways of going to Mars. In one case we use the impulse type rocket, and in the other we use the constant thrust. ~~Light, heavy weight, low specific fuel consumption.~~

You will see here for the low thrust system it takes 127 days to escape from the earth satellite orbit out into the Mars orbit. Then we coast down for 268 days with a total time of 1205 days to complete the journey.

With the impulse rocket it takes 915 days. So you see there is not a great deal of difference in total time, largely because the waiting time comes in here. You have to wait until Mars and earth are in proper relationship to each other to come back.

Representative Van Zandt. Do you think it is worth taking out travel insurance?

Dr. Silverstein. There are other ways of going in which you can have a shorter time than this, except the loads you can carry will be less per pound of air frame you have. That is the thing you are always trying to weigh.

May I have the next slide here. (Figure 10)

Here you get a feeling for time. The propulsion time I was talking about was about 1,000 days with a thrust to initial weight ratio of 1 to 10,000, one pound of thrust for each 10,000 pounds of space vehicle weight. ~~of 10 to the minus 4, one pound of thrust for each 10,000 pounds of space vehicle weight.~~

You can shorten the time if you slide down this curve and get higher thrust value and get propulsion time down quite a bit. However, you are going to find sooner or later that you are not going to ~~not~~ be able to carry the payloads you want to carry.

Representative Van Zandt. This schedule is based on chemicals?

Dr. Silverstein. No; this is based on basically all systems.

Representative Van Zandt. All systems?

Dr. Silverstein. Yes. Let's go ahead now.

Now, since these electrical propulsion systems are the agreed key to all the ion plasma systems, I thought I would list for you the basic energy sources we have to work with, the types of generation we can use, and the actual accelerators or thrust generators. They are shown here, in Figure 11.

Basic energy sources -- chemical, radioisotopes, solar radiation, nuclear fission, and nuclear fusion. These are the types of methods we generat power by, either by radioisotope batteries, thermopiles, solar ~~batteries~~, turboelectric

generator, induction from moving plasma. Then we accelerate the fluid by these means: electric arc, ionic accelerators, plasma accelerators, or photon.

This covers pretty much the range of possibilities we see ahead. However, there are many things concealed within the separate objects listed.

Senator Anderson. Do you not think we ought to have copies of those charts for the record in order to make it possible for us to reconstruct some of the things you have said?

Dr. Silverstein. You can have copies of the charts along with a description of the whole thing. We will be very happy ~~to~~ let you have them.

Now let's try to get a little closer to descriptions of some of these things to see what they might look like. So far they are pretty much words. Go ahead with the next slide (Figure 12).

We are talking first about the kind of electrical power sources that are fairly common that we know of. What I have plotted here is the weight of these systems in pounds per watts of power against the number of days that you are going to use them. Because if you are going to be, ~~oh, in a flight~~, say, in a satellite flight continuously circling the earth, it may be ~~a long time,~~ that you need power, for a long time.

For example, we have a feeling ~~that~~ the source of power for Sputnik went out ~~after so many days~~. We may want to go

longer than that. This curve shows of the various systems we can conceive which might be the most effective.

We have listed here fuel cells, thermopile, and solar batteries which generate electrical current as a result of exposure to radiation ~~to~~ from the sun, shown in two ways: one, in which they are getting sun half the time, and the other full time, which is a function of whether or not they are being shielded by the earth in their passage.

Representative Van Zandt. At that point, in regard to Sputnik I and II, have you any information that this type of battery was employed by the Russians in those two satellites?

Dr. Silverstein. The only information I have is based on secondhand information obtained as a result of discussion of our director, I think, with one of the scientists, Russian, who claimed for Sputnik I they were putting in 80 pounds of battery. With 80 pounds of battery, the thing calculates about right from this chart for the length of time it ran.

Representative Van Zandt. In other words, the answer is yes?

Dr. Silverstein. The answer is yes, if my information is correct. It is not factual. So it is my feeling that they used a battery system.

These batteries, of course, are very much more advanced.

I want to call attention to one point. You see what we have here. We have values of 2 and 1 pounds per watt. These

values are far, far too high. ~~That corresponds to a thousand pounds~~. One pound per watt is a thousand pounds per kilowatt for this type of equipment.

In order to make these things fly, these space systems fly, we are going to need to get the whole system to values closer to 10 pounds per kilowatt, or lower than that if we can.

So that these systems for long term use for primary propulsion for space vehicles are basically out. None of these systems shown here will provide it. However, they will provide and can be used for very small powers you might need for instruments or something like that for reasonable lengths of time.

Representative Van Zandt. The question I asked you a moment ago, did I understand your answer to include that these batteries were solar? ~~system?~~

Dr. Silverstein. No, no. My answer was they were cells more like the chemical ~~our mechanical~~ cells we have now. The most advanced type in conventional batteries.

Representative Van Zandt. Thank you.

Dr. Silverstein. Let's get around to some of these arrangements for generating power. I think probably these have been discussed with you.

In Figure 13 ~~Here~~ we have a system in which we have a nuclear reactor here, and the nuclear reactor has a liquid metal, ~~perhaps,~~ passing through it to cool it and take out its heat, passing

SECRET

through ~~a~~ the upper loop system ~~here~~. We could consider ~~this perhaps~~ the upper loop through the reactor perhaps to be lithium ~~through here~~, and it might be sodium in ~~this~~ the lower system. ~~Then we take this~~ We take the hot material ~~and expand it through a turbine here, a hot vapor~~, which might be hot sodium vapor, and expand it through the turbine and take work out of it. As we take work out of it, of course, it will cool down some but there will be a lot of heat left in, and we will have to take the material over through a radiator to radiate this heat out into space, and then we can return this material back to the cycle. How?

We have a shaft here in this turbine. We pump ~~this~~ the material back through the cycle again and also got power left over that we can drive the electric generator again.

This system is able to generate electric power which we are going to need in all forms of ion and plasma accelerators we are talking about. Somewhere or other we have to have an electric machine in here. This is one way to do it.

As you all know I think -- and this remark was made a few minutes ago -- electrical systems are heavy as now designed. But no effort really has been made to lighten them because there has been no need for it. However, I am sure that their weight can be reduced to a quarter very easily by simple design, and perhaps by breakthroughs as a result of research we can reduce the weights much below this. There are possibilities that have been suggested at our laboratory, and I

SECRET

think other places, for reducing the weight by concepts of superconductivity, reducing the termperatures of these materials down to the point where the resistance of material reduces practically to zero, or to zero. These studies are for research, and I am sure we are doing some work in it now and I think others are. I think we will see some progress ahead as this work is reported.

I think we can count on reducing the weight of these things markedly.

The reactor system here is not a great advance in this case above our present reactor technology. Its weight is not as critical as you might think because the major weight in the system does not lie in this area.

The next slide, figure 14, ~~This is the next slide.~~ ~~This is~~ is a little closer view of this thing. I do not think you are too interested in the temperatures, perhaps, but here we see the reactor again and these various complements I mentioned -- the reactor, and heat exchanger, pump, and radiator we have here.

Now the shield here is an important item because someplace on this space ship we want to have men eventually, and we will have to shield this reactor , or the passengers from the reactor. One nice feature here, of course, is that we do not have to worry about air scatter when traveling in space. ~~So~~ Therefore, the shield does not have to encase the reactor as completely as is required in the earth's atmosphere, ~~we do for men carrying on nuclear things~~.

There is no scattering of radiation back into the passenger compartment. So the shielding weight is greatly reduced, but nevertheless you have to carry some shielding and it becomes an important part of the weight. So this reactor in no sense is the overall determining factor in the whole system; rather some of the other components.

This system in order to work may have to rotate about its axis, because basically we have condensers, we have a steam system. Perhaps it will be sodium vapor here, and we are trying to take the liquid from the vapor; in order to do that we may have to rotate the radiator. ~~this. You may have to create this artificially by rotating the bodies.~~

The next slide, figure 15, shows something like this. Here is a very hypothetical type of thing. The reactor component we looked at a minute ago might be at one end of a 600-foot long pole, and since it is gravity-free space you do not have to worry about the weight distribution. You might have to worry about the forces along the axis.

This is the radiator, the heaviest component. We design the shield here for separation of the passengers who are down in the crew compartments. ~~here (indicating.)~~ The passengers might be rotated also to give them some feel of gravitational pull, the component associated with centrifugal force of rotation. That is a detail.

The next slide, figure 16 illustrates ~~Here is~~ the point I was making aminute

ago. When we get out to the sizes we might be interested in, which is in the range of 20,000 kilowatts for some reasonable sized mission, this is a breakdown of the weights of that system I showed you a minute ago. It includes a radio generator. You will see the reactor is not a real large part of it, and the design of this reactor is not unconventional in the truest sense. It is some advance over present reactors. Not a great deal.

The shield weight in the low thrust ~~unit per killowatt~~ system becomes a very large part. However, since it does not change a great deal as we get ~~down~~ to the higher powers, you can see it becomes a smaller part out here as we go out to larger power systems.

The next slide, Figure 17 shows one of ~~This is~~ the electrical systems I have been talking about. ~~They are not the only way of getting electrical power in space.~~ We can imagine, of course, that we can get power by taking the sun's radiation, allow it to evaporate ~~against~~ a fluid, just as we do in a steam system; take the heat and make steam and drive a turbine with it, and then drive an electric generator. And this is a system for doing it.

Again, some of these things lead you to wonder whether you are in fact still sane, but we are talking about a balloon here which is one-thousandths inch ~~think~~ thick, made out of mylar, and some balloons we are putting up now are not much thicker than that. 1260 feet ~~in diameter~~. Total system weighs 110,000

pounds. The balloon itself weights 36,000 pounds. The sun comes down through the ballon, ~~here~~, is reflected off the mirror ~~of here~~ on to evaporators, and we pick up the sun's energy here and go through our cycle.

Representative Van Zandt. At what altitude?

Dr. Silverstein. This is in space.

Representative Van Zandt. In space?

Dr. Silverstein. Yes. You see there is quite a bit of power. The sun, if you take the actual watts that are delivered on a square foot of surface, gives off ~~there is~~ considerable energy ~~by the sun~~. Particularly in space you have no absorption by the upper cloud layers. So this system here, if it is a possibility, is a system based on weight.

What we have done ~~on this slide~~ is to try to add up, based on our studies -- and we carried studies along for sometime -- what the competitive position might be.

Representative Price. How long have your studies been?

Dr. Silverstein. We have been working in this area for several years now. The work has been in the study phase, and some of it has gotten into experimental phase. I perhaps will show you some.

Chemistry rocket work, of course, is very old. We have been working in that field for 15 years. The space systems, we have been working for about the last year more intensively, but very casually, just looking around. ~~sort of.~~

~~SECRET~~

In Figure 18 ~~Here~~ we are trying to add up weight, and you recognize here certain types. This is the nuclear turbo electrical system I went into some detail on, and you see it here in terms of electrical power output in kilowatts, and this is keyed in here, ~~some in size,~~ to the different kinds of applications you might want.

More power is required for these longer-time applications and less power for the satellites here.

Then the power plant weight. We want to get the lowest possible value here, and you see it lies along the line here like this. ~~And the~~ The nuclear turbo electric with no shield and the solar system are fairly competitive.

When we start adding heavy shields, ~~we~~ the nuclear system becomes a little heavier . Out in the large power ranges which we are mostly interested in for these longer-range flights the nuclear and solar systems ~~two~~ are directly competitive.

We put a spot out here on the fusion system and the validity of the spot is very much in question. I do not think until this field moves quite a bit further than it has, that we are entitled to really locate the point.

Certain assumptions have been made here regarding the weight and coils and all, but I question ~~it~~ them. I think these numbers depend also on the rate of progress we make in the development of electrical power systems, generators, for

example.

I have a feeling these numbers could be cut down a great deal with adequate research. It may greatly influence the direction of the field we are moving in.

Let's go ahead. We have talked so far about generating the electric power through nuclear into the thermodynamic cycle and into electric generators. Now we are going to use. ~~We~~ the electric power. We have electric power ~~here~~ and are going to put ~~that~~ it in either a magnetic field or an electrostatic field~~, the ionization chamber~~ and accelerate the particles. Basic components of such a system are shown in figure 19.

I am going to show some of the things we might use to accelerate particles.

In figure 20 ~~here~~ is one system called the ion electron source, due to a man named Stuhlinger it was brought to our attention.

What you do is ionize cesium vapor which passes up through a series of plates, and there is a potential difference between these plates and ions that are formed. The positive particles are accelerated through the~~se~~ plates and out of the jet. ~~here. The electrons are taken aboard these plates and are boosted by electric power source out and discharged here.~~ Electrons are concurrently discharged from the electron generator.

Characteristic of this system, it is necessary that the space charge due to the~~se~~ positively charged ions issuing from the jet be very ~~ions issuing from here be very~~ rapidly neutralized by the electrons ~~ions~~. Otherwise we build into space here a charge and cancel the thrust. This system has possibilities. It ~~is in the~~ early stages of its thinking.

It requires research and efforts to find out just how effectively you can cancel this space charge by bringing the electrons and ions together -- how large a jet you can make and still cancel the charge. There are many scientific problems here. This represents one type of system.

Let me have ~~the next slide~~ figure 21. This is another one. This is called the Bostick's plasma accelerator. It differs from the ion simply by having both the positive and negative charges together. A plasma is a mixture of ions and electrons. So that here in this generator what we do is to discharge a capacitor across ~~to filament and in the discharge we filter the field here. Because of the forces on this field the material ejected from the end of the plug here goes off into space.~~ two electrodes to produce an arc. Current flowing through the arc produces a magnetic field. The magnetic field and the current interact to produce a force that accelerates the plasma into space.

There is every reason to believe a system like this will work. We have played with systems like this and feel they do have possibilities -- experimental!

~~Here is~~ Figure 22 shows another system we are working with now for producing acceleration of plasma and ion. What we do here is take this electric energy we have created and we flash an arc across ~~this~~ a section near the right end. ~~here~~. This arc travels down two rails and since it is highly ionized it can carry a current, and we use a magnetic field here to accelerate, ~~and accelerate~~ it out the back ~~here~~ as a beam. This system we are experimenting with and have investigated at the laboratory.

figure 23
The next slide, I think shows you a small system we built and demonstrates the fact we were getting thrust on it. To do that we put a pinwheel out, ~~here.~~ to the right. These are the rails, to the left. This is the jet and this is the spinning pinwheel that is being accelerated by this beam coming out of the back of the accelerator.

The next slide please.

~~This~~ figure 24 is another system that can be used. We do not look upon it with too much favor. But you can take the current that you generate in this system and cause an arc to form across here between an electrode here and the wall, and then by passing a gas through the system and heating it we can create a plasmic flow.

Representative Price. Does that have any relation to some of the things they are working on in the controlled thermonuclear program, what you have shown us here?

Dr. Silverstein. In a sense there is a relation. This one has no real relation, but the fundamental principles of the thermonuclear pinch ~~pin~~ system, I would say, are not too greatly different than the ones showed for the ~~plasmic~~ plasma accelerator. In other words, the same principle of carrying a current within a plasma and then allowing it to be pinched down as a result of its magnetic field.

These same things are implicit in the ~~plasmic~~ plasma generator I showed you before. There is a relationship. The application

is the difference.

Representative Price. How do you coordinate the work you are doing with other agencies of the Government that are working in similar fields?

Dr. Silverstein. We have many means of coordination. The principle one is the subcommittee structure of NACA. The NACA has the main committee and many subcommittees. We have a propulsion subcommittee and we have other subcommittees, and on the subcommittees we have representation from all of the military services, we have representatives from industry, and the AEC, and these people continually carry on coordination. We have other means of coordination through our headquarters staff, through visits of our staff to other agencies.

We do, I think, keep in touch. I think other people keep in touch with us.

Our laboratory, I think -- for example, last year we had some 4500 ~~fivitors~~ visitors during the year, which gives you an idea there are a lot of people coming in to find out.

Senator Anderson. You keep in touch with Los Alamos a little bit too, do you not?

Dr. Silverstein. Oh, yes.

Colonel Armstrong. I am a member of one of the subcommittees on rocket propulsion, so I keep them informed what we are doing.

Dr. Silverstein. Let me have the next slide, figure 25.

There is another interesting thing here. ~~This is some-thing~~ you calculate, but this, this is called a radioisotope sail. Here we depend upon having a sail which on one side ~~-- here is a cross-section. Up here we have what might be called a reflector, and we allow alpha particles to move down this way.~~ alpha particles given off by a radioisotope, whereas the alpha particles are permitted to travel down in the other direction. Their reaction against the sail, coming out on one side and being restrained on the other, gives you a force which will move the body.

We have calculated the thrust it is possible to reach with ~~these~~ this sort of thing~~s~~. We previously ~~have~~ talked about thrust with 10 to the minus 4. This is minus 6. We are talking about thrust of one millionth of pound~~s~~ to a square foot of sail. It is very small but you do not have the resistance there.

Colonel Armstrong. Might I interrupt you, sir? We tried this and it worked. We measured the thrust and it worked.

Dr. Silverstein. Yes, it will work. The question is, is this the best way to make it work?

There are many things that will work. This is the problem we have all the time -- you want to get the best one. I am quite sure it will work, but I am not sure it is the best way to do it.

The next slide.

~~Here~~ Figure 26 is another one in which you use the sun's rays directly. The sun rays, of course, can be considered as

photons that are impinging on this sail and they are driving it. For years this has been a laboratory experiment of having light fall upon a body, and I think you might have observed some of the things that are caused to rotate. If they happend to rotate backwards, that is another thing.

This is another method of propelling yourself in space. Again I do not know how this one -- this gets to be a little farfetched, but maybe not. We will have to look and see.

~~The next slide.~~

~~Here what we tried to do in~~ In the next three slides ~~is to kind of~~ we have tried to put the stuff together that we have been thinking about, to see where all of these different systems fit together, and we took some typical trips we could imagine.

For example, Figure 27 is for a roundtrip to the moon with an eight-man crew landing and exploring the moon. They had a basic payload of 10,000 pounds and another 15,000 pounds of equipment to help them in their exploration.

We said, what would the overall weight of the system be to do this mission? We looked at the chemical rocket and we looked at the nuclear rocket with an impulse of 1200. That is about a 5,000 degree Fahrenheit rocket. And we looked at the ion system to do it. We found in looking at it the weights you end up with -- ~~and~~ that these ~~are the~~ weights ~~shown over here~~ -- vary from about 350,000 pounds here down to 100,000 pounds. ~~here~~

In looking at it closely, we see there is not a great deal of difference in weight between the high energy chemical rockets and the best of the systems. Right here this is electric without a shield. We know we will need some shielding.

So for this mission, a mission of this length, which is just to the moon, from an engineering point of view it would appeal to us to try to do the thing ~~in this fashion~~ by means of Chemical rockets because it requires the smallest extention of our present technology.

We could actually do it with ~~these~~ chemical rockets, trying to use things that exist, and I think there is a possibility of doing it. Again it would have to be considered very carefully if going into an engineering project. But certainly we do not need anything very exotic in the way of powerplants to conduct this particular trip.

Senator Anderson. What sort of lift would you have to have to get that off the ground, this chemical rocket in the very first column? What sort of lift are you going to have to have?

Dr. Silverstein. For this system you would need about 450,000 pounds of thrust to get it off the ground, that much rocketry.

Senator Anderson. About what the Atlas has?

Dr. Silverstein. Well, the Atlas has about 360,000 pounds at take-off. These are launched from the satellite. These are not from the ground.

Pardon me. I left out a very important statement. It would still be true it would take that thrust to get them off the ground, but all of these are launched from a satellite.

Senator Anderson. In other words, if you can get the platform up, you can then go on?

Dr. Silverstein. Yes. I am very sorry. I should have made that clearer.

Let's go to the next slide.

In figure 28 ~~Here~~ we have a trip further away. This is an unmanned Mars trip -- satellite to satellite again. Payload, 2,000 pounds. Unmanned, the payload is small.

Here again, comparing the chemical rocket with the nuclear electric ion system, I think you can see that for these small payloads again it probably does not pay to go to the more complicated systems. The chemical propellant here is about on a par ~~part~~ with the ion system for this mission.

Senator Anderson. How do you get up to the satellite?

Dr. Silverstein. From the ground to the satellite you have two choices basically. That is what I discussed in the early part of my talk. Either take them up with chemical high energy rockets or take them up with nuclear rockets.

I think you will find if you take them up with the chemical rockets they will weigh more, the whole system will weight more, but you will probably be able to do it a little earlier with the chemical rocket, because the chemical rocket is

basically an easier job. We have a lot under our belt and the problem is further along.

Senator Anderson. It is no problem when something is in orbit up there to take a rocket off and still make connections up there?

Dr. Silverstein. No; I would say this is a thing that has been demonstrated. I think you need auxiliary power, but this I have not discussed. I only talked on how to get them there. You need the power after you get there to connect them, to rendezvous. You need other power then.

Mr. Ramey. Could you get from earth to Mars with nuclear power directly?

Dr. Silverstein. I think so.

Mr. Ramey. Without an intermediate satellite step?

Dr. Silverstein. I think you could, but I think it might be -- I am not sure of your payload. I do not think we have made that study, have we John?

Dr. Evvard. I do not know.

Dr. Silverstein. I do not recall that study. I think you can do it would be my guess, but the payload probably would not be high, as high as you would like.

Let's go to next slide.

~~Here~~ Figure 29 is where it begins to pay off to go to the advanced systems. Now we are talking about roundtrip Mars expedition with eight-man crew, satellite to satellite, landing and

exploration, with total payload of about 110,000 pounds. You can see, if you used conventional ~~low-grade~~ chemical rockets, ~~with our best~~ we would need 7-½ million pounds, with our best chemcial rockets even, we get about two and one-half million pounds. ~~Low-grade.~~

Now we are beginning to make gains here. You can see the nuclear rocket is down to around 400,000, ~~and these are~~ electric ion ships are in the same general ball park. So these two things, based on the best calculations we can make at current stage, are somewhat competitive.

You might say this system (nuclear rocket) ~~(interesting)~~ is further along, and those that argue the other way will say, that the nuclear ~~this system is~~ electric system is further along because the nuclear part is greatly easier ~~than this system because the machinery part in this might be easier than this~~. I leave that for a matter of discussion. I do not think it can be answered ~~definitively~~ now.

I think that, sir, completes the slides I have, and I will be glad to answer any questions.

Dr. Evvard. Could I make one comment?

Representative Price. Yes.

Dr. Evvard. This slide might suggest that the nuclear rocket is competitive with the nuclear electric system on the estimated initial weight, and hence you would never use the nuclear ion system. I think this was concluded by the previous speaker. However, you must recall that the specific impulse of

of the nuclear electric ion system is on the order of 10, 12, 14 times as high as it is for the nuclear rocket. So that, if you were going to make more than one trip, you would only have to put one-tenth as much fuel into the sky for the second trip as you do for the first trip.

Senator Hickenlooper. Wait a minute. You left me there.

Dr. Evvard. If you are going to establish, let's say, a street car between the earth and Mars satellite, or satellite to satellite, it takes you roughly 10 times as much fuel by means of nuclear rocket, maybe 12 times as much fuel using the nuclear rocket than it does for the ion propulsion system. Now the total weight is about the same initially due to the fact that there is so much more weight in the generating system. But if you make a second trip, if you go there, come back, and then go again, on the second trip you only need one-tenth as much fuel for the ion propulsion system as you do for the nuclear rockets.

Senator Hickenlooper. I will come back some other day.

Dr. Evvard. You already have the electric generating equipment put up in the sky. So the amount of extra supplies you have to bring from earth up into a satellite for the second trip is roughly one-tenth as much.

Colonel Armstrong. We would like to avoid the filling stations in the sky. We would like to go from earth up there.

Dr. Silverstein. There are possibilities both ways.

Senator Hickenlooper. I still cannot follow what you are saying. If I start my automobile out of the garage this morning it will take so much gasoline to push it, but I come downtown to the office building and then turn around and go back and start out tomorrow morning my automobile takes a lot less gasoline to get it out of the garage?

Dr. Evvard. The total weight is, say, 600,000 pounds. I do not remember the figures exactly, that you have to put into the satellite for the first trip. On the nuclear rockets of this 600,000 pounds a substantial portion will be fuel.

Representative Hosmer. Consumable fuel?

Dr. Evvard. Consumable fuel.

If you made the second trip you would have to replace that much consumable fuel.

Senator Hickenlooper. It is the same principle, that the second morning it does not take as much gasoline in the tank to push the car out of the garage.

Representative Holifield. In the first trip you go up to the top of the hill and on the second you coast back to the garage.

(Discussion off the record.)

Senator Hickenlooper. I still want to get this straight. Do I understand the reason it will take a lot less to take this thing off again is that the fuel load is lighter?

Dr. Evvard. Yes.

Senator Hickenlooper. That is the same as the automobile analogy.

Representative Holifield. When you start from the earth you are starting with gravitation and when you start from the satellite you are not.

Dr. Evvard. The fuel load for the nuclear rocket is ten times the load for the ion rocket. Initially this weight is made up in the weight of electrical equipment which, once you got it into the sky, you do not have to put it up the second time.

Representative Price. Where do you leave it?

Dr. Evvard. I think the point is that, perhaps, if you are going to make more than one trip, the ion rocket is still competitive for a Mars journey.

Senator Hickenlooper. I think maybe I am cutting through this fog of confusion. I understood the original premise to be if you started out from here and went to the moon and came back here and then took off again and went to the moon it would take a vast amount less to get you up there the second time.

Now somebody else tells me what you meant first was you take off here and go up to the satellite and then take off and come back to the satellite and take off again. I can understand that, but I did not understand that was it.

Dr. Evvard. From satellite to satellite.

Senator Anderson. Before we get confused again, let's start on the next step.

Dr. Rothrock. This completes our presentation.

Colonel Armstrong. I think Dr. Silverstein said something that should not be forgotten. He said the machinery that goes into the nuclear ion device is a more complicated situation than that which goes into the nuclear rocket device.

Senator Anderson. I want to say this has been a most interesting presentation. I am happy to know there are people who are continuing to think about this even though a great many people thought they did not need to think about it.

Representative Price. Do you do development work there on the ions, studies?

Dr. Silverstein. We --

Representative Price. Research?

Dr. Silverstein. We do basic research at our laboratory, and all we are trying to find out from studies of this general type is what are the things in which greatest emphasis should be applied, and then we do development work in that area. We are a research organization. There are times we cannot go out on the market and buy generators, ion generators, so we create them for our own use.

Representative Price. Do you do theoretical studies on these, Colonel Armstrong?

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Colonel Armstrong. The program we put off until tomorrow,

secondary nuclear auxiliary power -- this is a very small nuclear device producing electrical energy, which is one step along the path he was leading you a little while ago, of then using that for a steering device for steering the satellite in the sky and moving around. This is not a theory, this is something we are cutting metal on now. ~~This we~~ We will have this presentation tomorrow morning.

Dr. Silverstein. This whole area is really quite young. I think we all recognize that, and it is going to take a great deal of work all the way through it to pin down these things that we vaguely see, in some cases see better than in others. I think many aspects should be supported. Without it I think there will be very little progress.

These things seem to be a little bit far off but actually they are not too bad. Actually the hardware is not so far away as it looks. You can do these things. There is nothing here I showed you that you cannot do.

Representative Price. You say you have had studies for several years. How many years?

Dr. Silverstein. Actually we started a group studying in this area, I would say, almost two years ago. But a year ago we emphasized the work. In fact, I think John was put in charge when we emphasized the work.

Senator Anderson. I think it might be well, Chet, if we

ask them to put SNAP on early tomorrow afternoon and go through the other things tomorrow morning, if you prefer to have it done that way.

If there is no great objection, we will try to have SNAP at two o'clock tomorrow.

Mr. Ramey. The Department of Defense will give its presentation in the morning.

Representative Price. Are there any questions of the NACA people?

Gentlemen, you have made a fine and very interesting presentation. We appreciate your kindness and courtesy and we have had a very interesting afternoon.

Dr. Silverstein. We have been happy to do it.

Representative Price. We will recess then until 10 o'clock tomorrow morning.

(Whereupon, at 5:40 p.m., the joint subcommittees recessed until 10:00 a.m., Thursday, January 23, 1958.)

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~~CONFIDENTIAL~~

TYPICAL SATELLITE TRAJECTORY

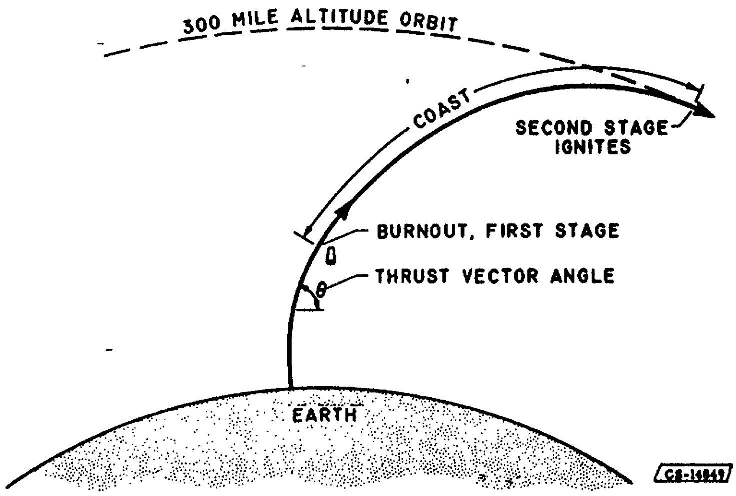

Figure 1. (UNCLASSFIED)

THEORETICAL PERFORMANCE OF $F_2 - H_2$

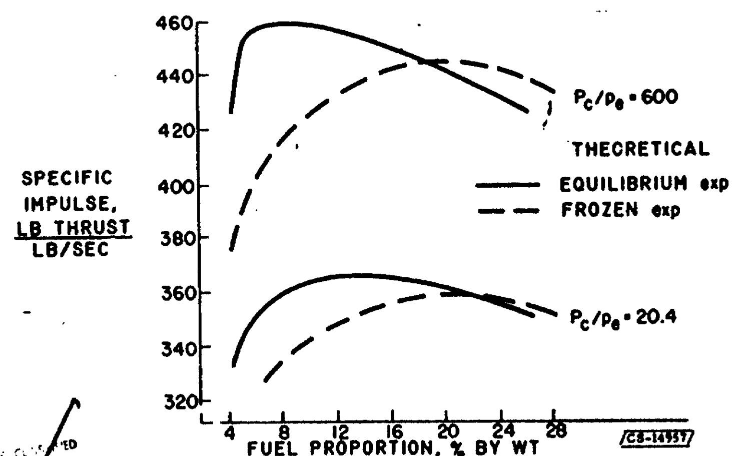

Figure 2. ~~(CONFIDENTIAL)~~

CONFIDENTIAL

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7/1/87

Part of Document 5438 (1 Secret, 7 Confi)

EXPERIMENTAL PERFORMANCE OF A
5000-LB THRUST REGENERATIVELY COOLED
ENGINE USING H_2-F_2

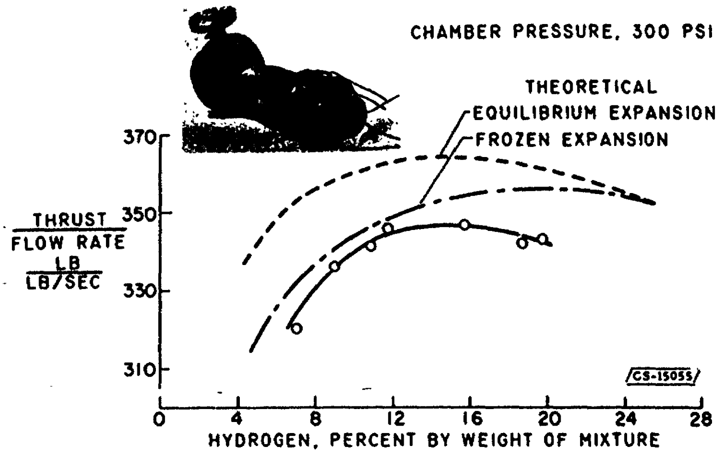


Figure 3. (~~CONFIDENTIAL~~)

VEHICLE WEIGHT COMPARISON MANNED
SATELLITE MISSION
2-STAGES

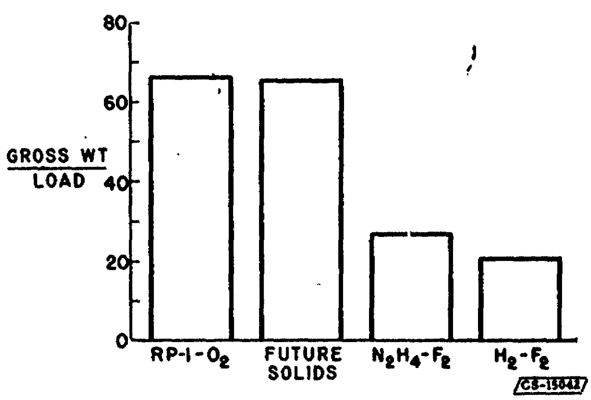


Figure 4. (~~CONFIDENTIAL~~)

4861

SPACE PROPULSION APPLICATIONS

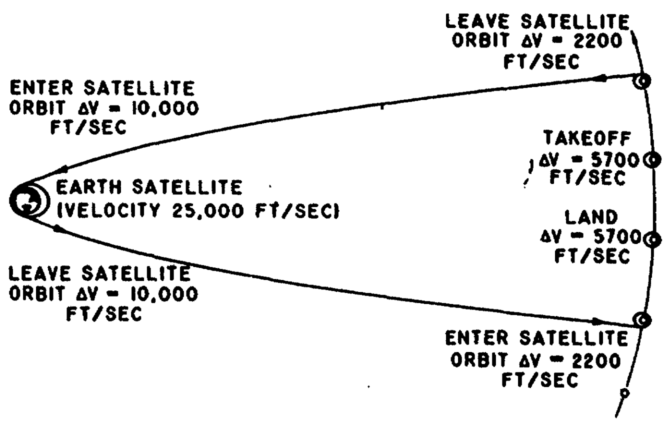
1 INCREASE LIFETIME OF LOW-ALTITUDE SATELLITE
2 CONTROL AND ALTER SATELLITE ORBITS
3 LUNAR AND INTERPLANETARY EXPLORATION
4 AUXILIARY ELECTRIC POWER

C-46483

Figure 5. (UNCLASSIFIED)

MOON LANDING

DEPARTURE FROM EARTH SATELLITE PLATFORM



VELOCITY REQUIREMENT

INITIAL (EARTH SAT) VELOCITY 25,000 FT/SEC
MISSION VELOCITY 35,800 FT/SEC

CS-14803

Figure 6. (UNCLASSIFIED)

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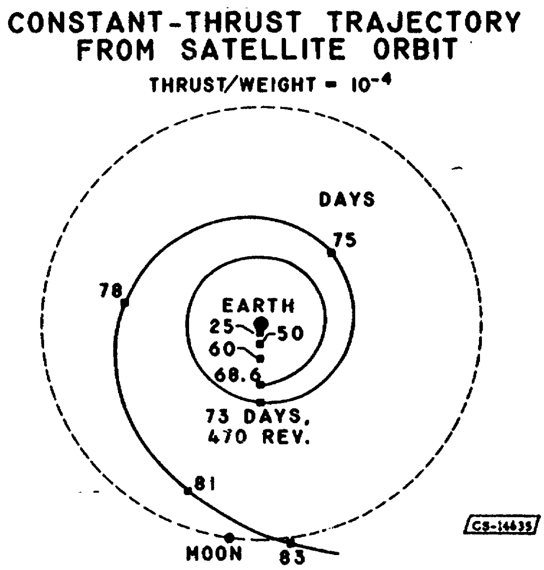

Figure 7. (UNCLASSIFIED)

PROPELLANT FLOW, SPECIFIC IMPULSE, AND JET VARIABLES FOR 50-lb THRUST

ENGINE	LB PROP / SEC	SPECIFIC IMPULSE, SEC	JET VELOCITY, FPS	JET POWER, KW
AB TURBOJET	0.50	100	3,200	109
SOLID FUEL ROCKET	.21	240	7,680	262
HIGH-ENERGY LIQUID FUEL ROCKET	.12	420	13,440	458
NUCLEAR HEAT TRANSFER ROCKET	.042	1,200	38,400	1,310
NUCLEAR CAVITY-REACTOR ROCKET	.012	4,000	128,000	4,370
NUCLEAR-ELECTRIC ION JET	.0025	20,000	640,000	21,800

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Figure 8. ~~(SECRET)~~

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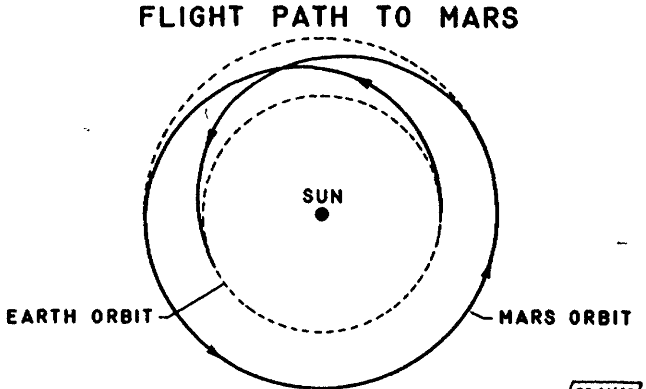
FLIGHT PATH TO MARS



TIME IN DAYS FOR MARS JOURNEY

SYSTEM	ESCAPE FROM EARTH ORBIT	COAST	DESCENT TO MARS ORBIT	WAIT	TOTAL
OW THRUST ($F/W_0 = 10^{-4}$)	127	268	85	245	1205
IMPULSE ROCKET	–	268	–	415	951

Figure 9. (UNCLASSIFIED)

EFFECT OF POWERPLANT WEIGHT ON PROPULSION TIME FOR MARS TRIP

(PAYLOAD = 0.5×TOTAL INITIAL WEIGHT)

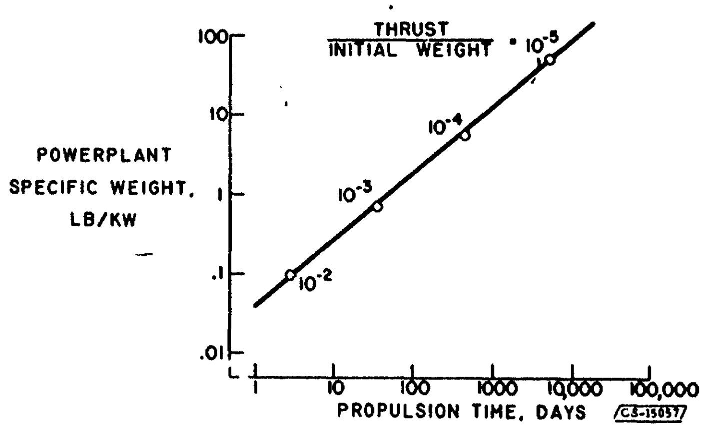


Figure 10. (UNCLASSIFIED)

ELECTRIC PROPULSION SYSTEMS

BASIC ENERGY SOURCES	ELECTRIC POWER GENERATORS	THRUST GENERATORS
CHEMICAL RADIOISOTOPES SOLAR RADIATION NUCLEAR FISSION NUCLEAR FUSION	CHEMICAL BATTERIES RADIOISOTOPE BATTERIES THERMOPILES SOLAR BATTERIES TURBO-ELECTRIC GENERATORS INDUCTION FROM MOVING PLASMA	ELECTRIC ARC CHAMBERS ION ACCELERATORS PLASMA ACCELERATORS PHOTON ACCELERATORS

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Figure 11. (UNCLASSIFIED)

LOW POWER ELECTRICAL SOURCE

CONTINUOUS OPERATION P_O^{210} ENERGY SOURCE

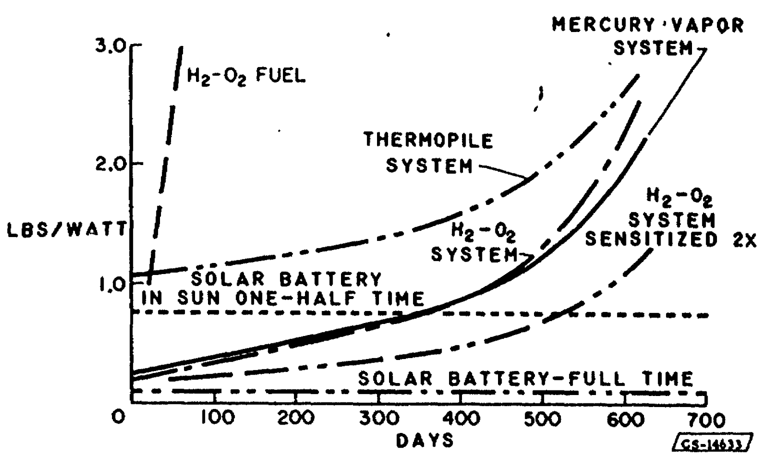

Figure 12. (UNCLASSIFIED)

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SIMPLIFIED CYCLE ARRANGEMENT
TWO LOOP

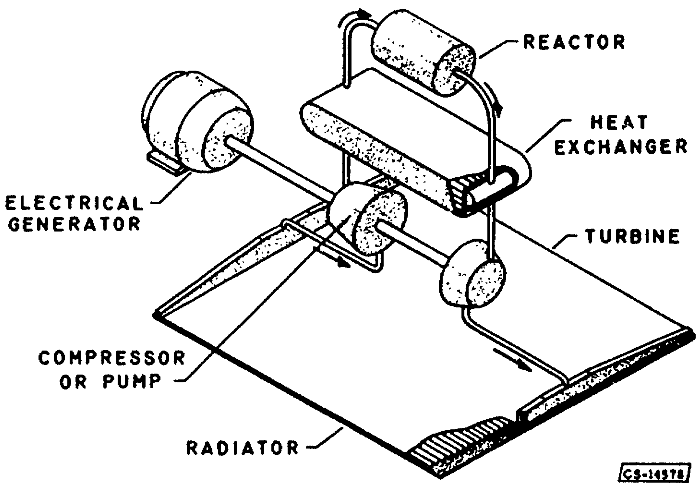

Figure 13. (UNCLASSIFIED)

SCHEMATIC SODIUM-VAPOR SYSTEM

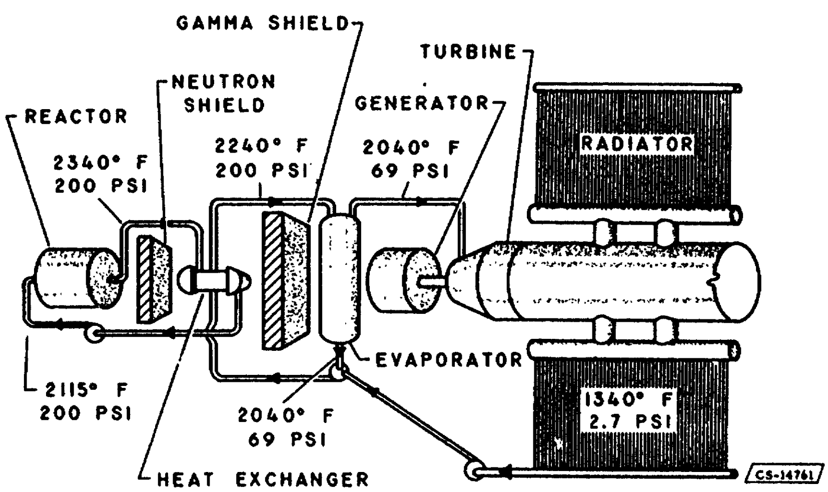

Figure 14. (~~CONFIDENTIAL~~)

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HYPOTHETICAL SPACE VEHICLE

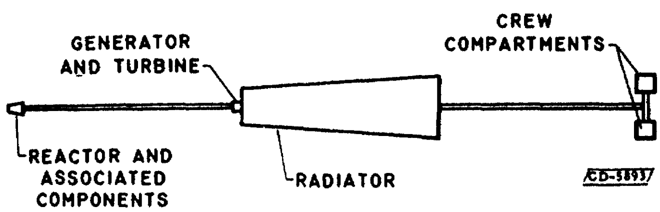

Figure 15. (UNCLASSIFIED)

WEIGHT OF POWER SUPPLY

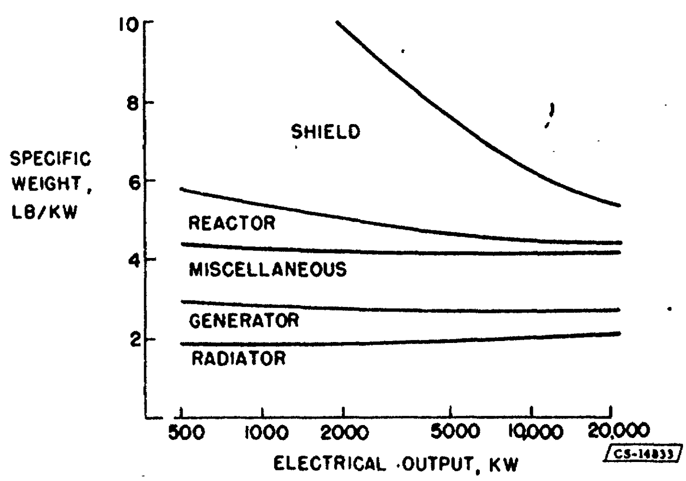

Figure 16. (~~CONFIDENTIAL~~)

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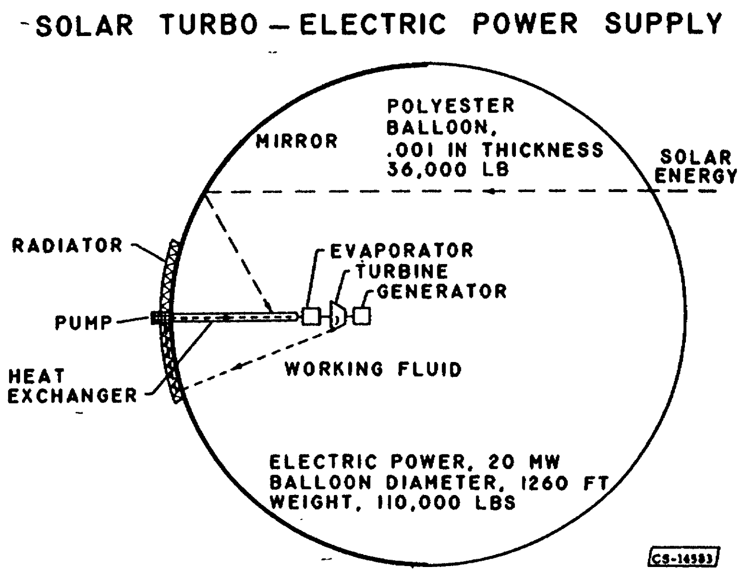

Figure 17. (UNCLASSIFIED)

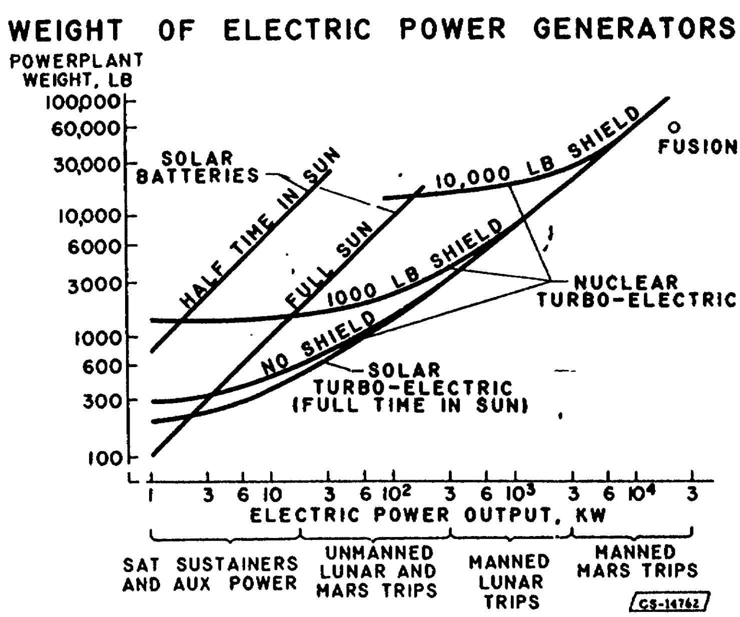

Figure 18. (~~CONFIDENTIAL~~)

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COMPONENTS OF ION THRUST SYSTEM

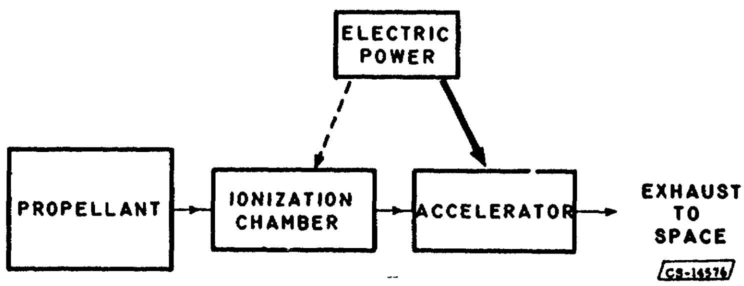

Figure 19. (UNCLASSIFIED)

ION AND ELECTRON SOURCE (STUHLINGER)

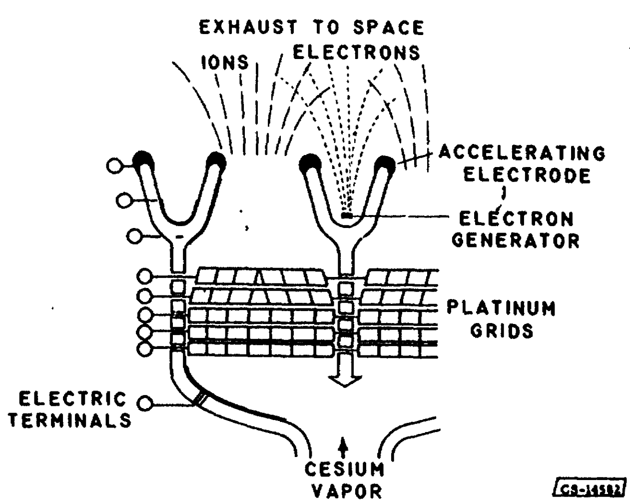

Figure 20. (UNCLASSIFIED)

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BOSTICK'S PLASMA ACCELERATOR

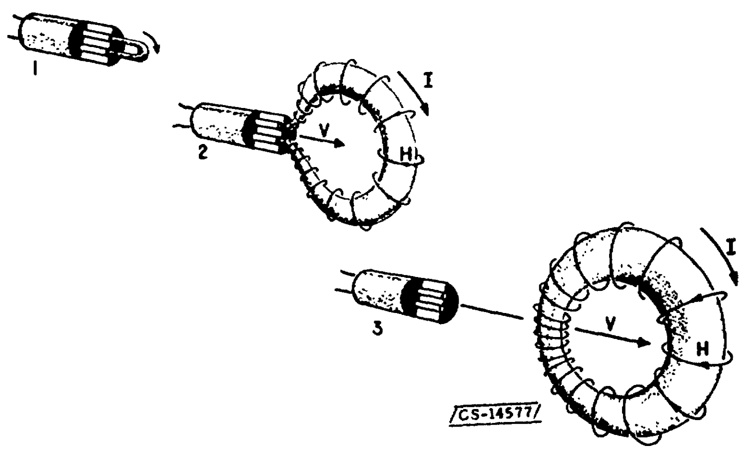

Figure 21. (UNCLASSIFIED)

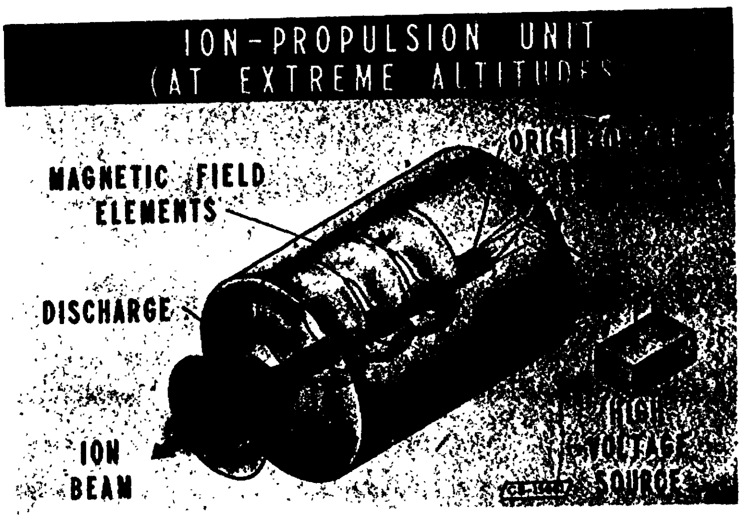

Figure 22. (UNCLASSIFIED)

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ION JET ENGINE

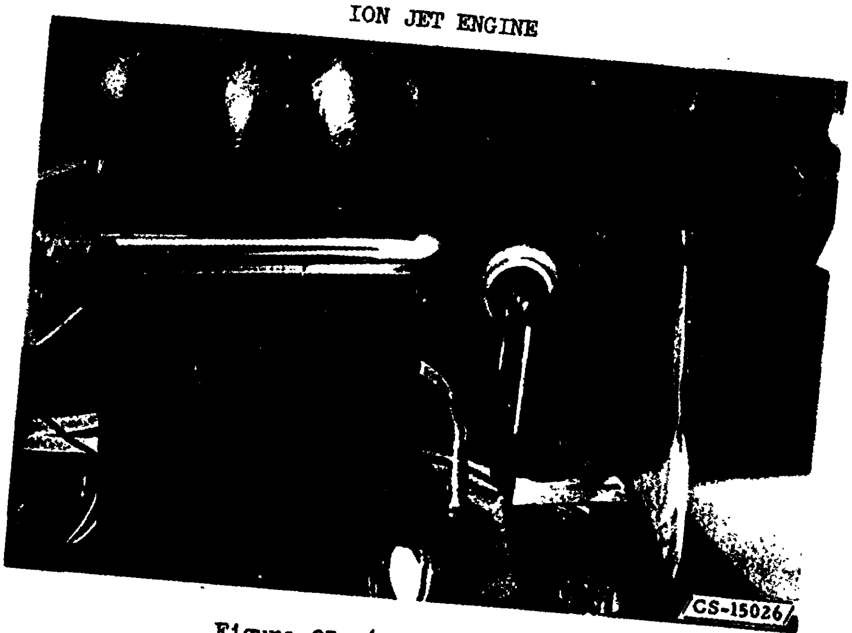

Figure 23. (UNCLASSIFIED)

ARC-JET PROPULSION SYSTEM

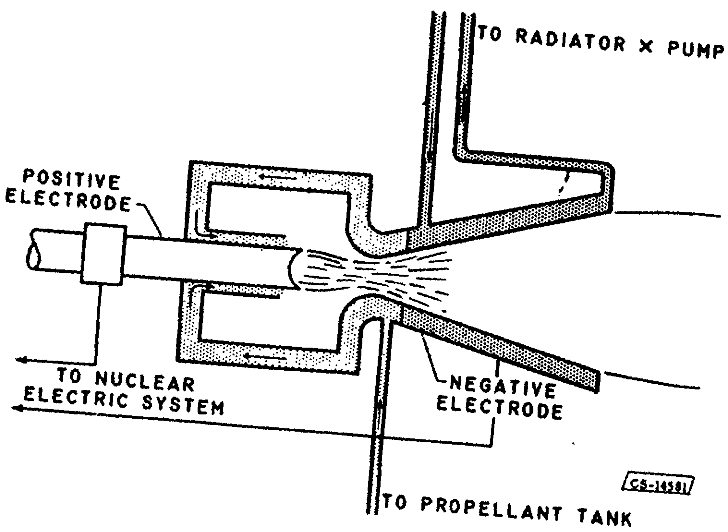

Figure 24. (UNCLASSIFIED)

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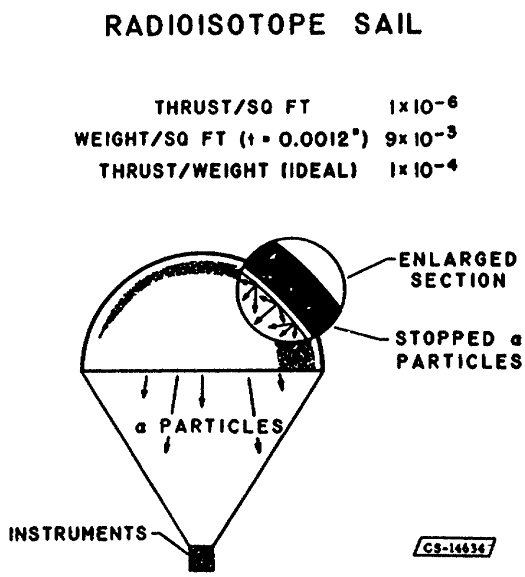

Figure 25. (UNCLASSIFIED)

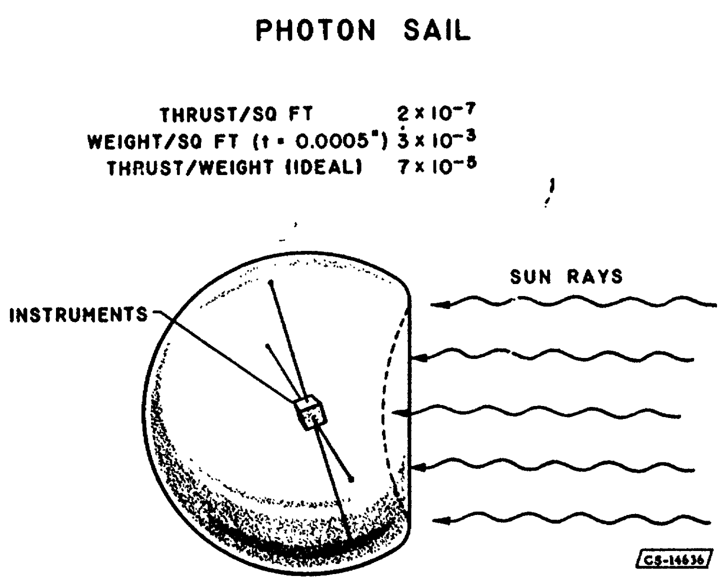

Figure 26. (UNCLASSIFIED)

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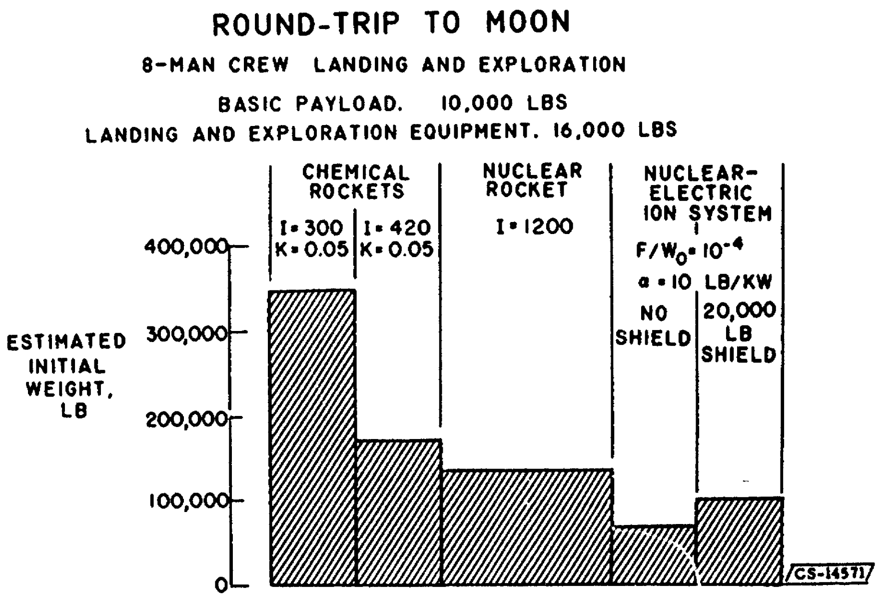

Figure 27. (~~CONFIDENTIAL~~)

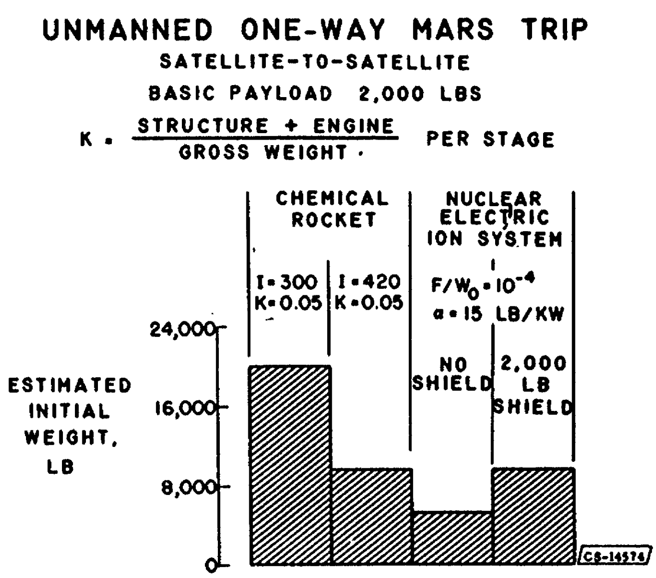

Figure 28. (~~CONFIDENTIAL~~)

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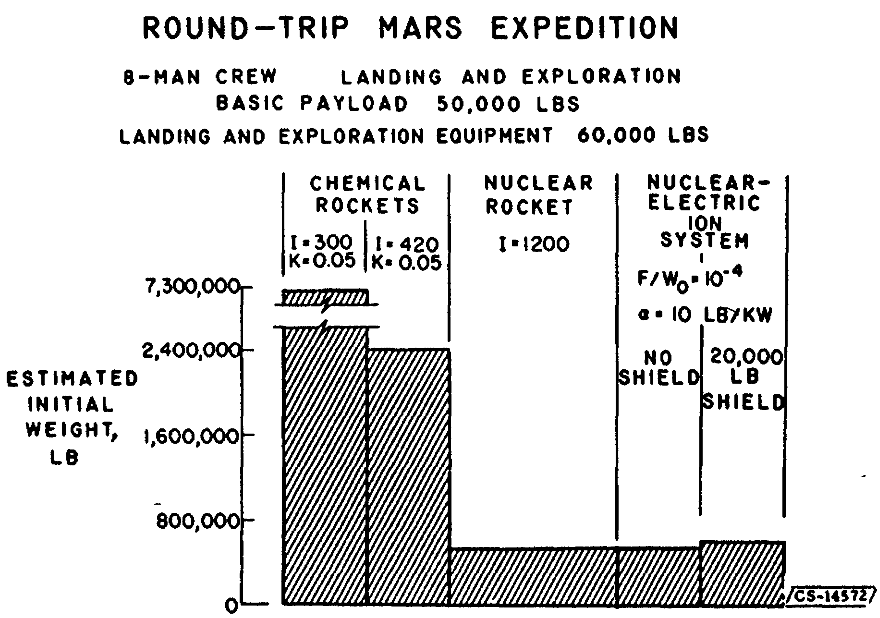

Figure 29. (CONFIDENTIAL)

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